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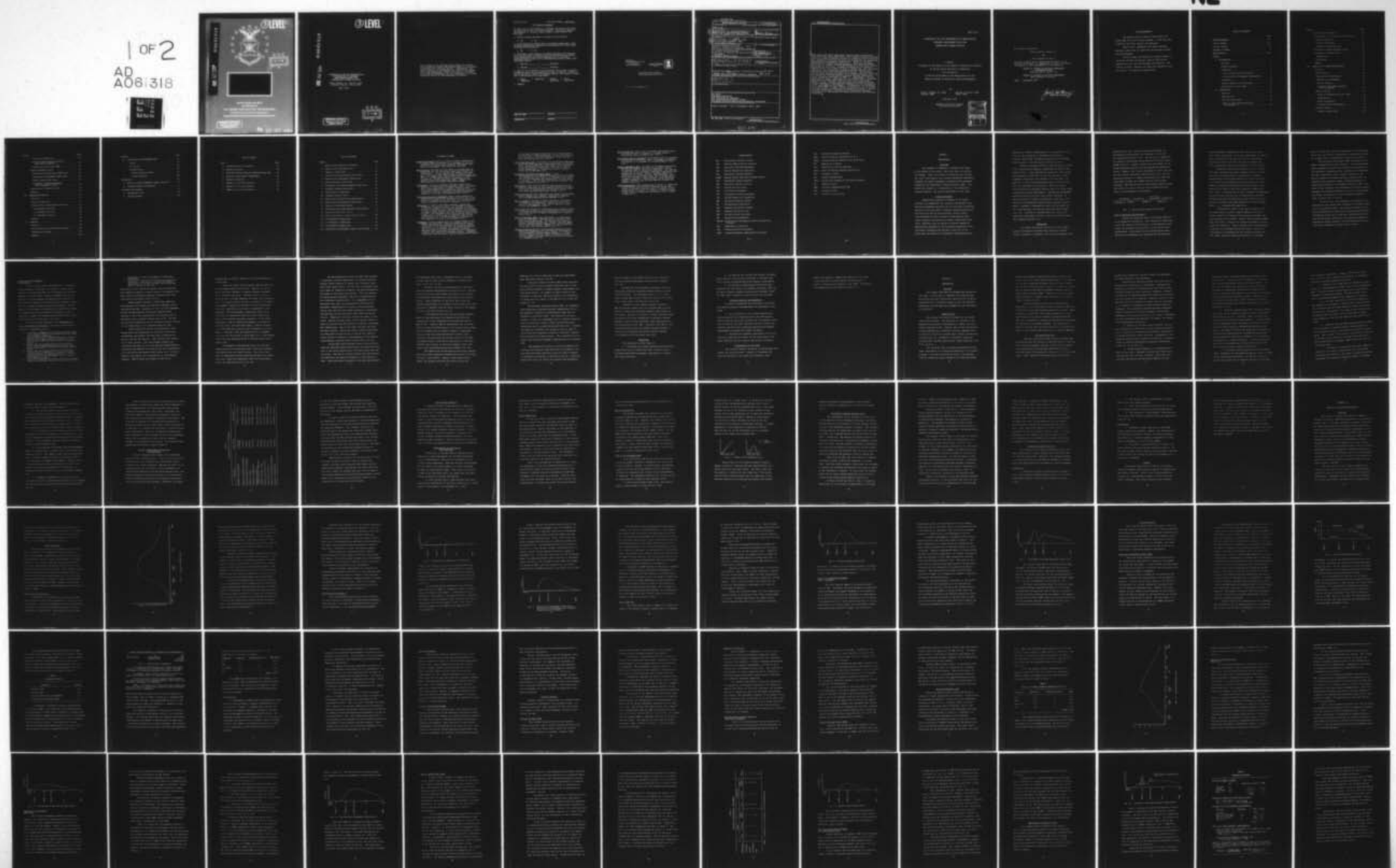

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A METHODOLOGY FOR THE DETERMINATION
OF MANUFACTURING PERSONNEL
REQUIREMENTS WITHIN THE
AERONAUTICAL SYSTEMS DIVISION

Fred A. Franke, Jr., Captain, USAF
Maynard B. Morris, Major, USAF

LSSR 9-78B

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This thesis had three objectives: identify basic manufacturing functions within major ASD fighter SPOs; identify program variables which are primarily manpower drivers to accomplish these functions; and, develop an efficient and effective methodology for predicting SPO manufacturing manpower requirements. Based on regulatory documentation, manufacturing engineering, manufacturing management, special reviews, and GFE management were identified as basic manufacturing functions. Program variables such as technical manufacturing risk, urgency of need, co-production, and contractor capability were identified as manpower drivers through interviews with senior ASD manufacturing personnel. The functions and variables provided the basis for a standard baseline curve and an algorithm to develop specific program manpower predictions. Using information available at DSARC II, requirements were compared against actual authorizations for selected SPOs. Predicted requirements peaked sooner and at a lower level than actual authorizations. However, the differnces were explained by the changing emphasis on manufacturing manpower and the introduction of new requirements after DSARC II. Difficulties in the methodology after DSARC III were evident and appeared to be the result of modifications, an effect not included as a variable. Overall, the model represents a methodology for determining manpower requirements by identifying the underlying factors and interrelationships.

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A METHODOLOGY FOR THE DETERMINATION OF MANUFACTURING PERSONNEL REQUIREMENTS WITHIN THE AERONAUTICAL SYSTEMS DIVISION

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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September 1978

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This thesis, written by

Captain Fred A. Franke, Jr.

and

Major Maynard B. Morris

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(PROCUREMENT MAJOR)
(Captain Fred A. Franke, Jr.)

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(Major Maynard B. Morris)

DATE: 8 September 1978

Jack L. McChesney
COMMITTEE CHAIRMAN

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We also impart our deepest and warmest thanks to our wives, Carolyn and Carolyn, and our families who endured this year with understanding and patience. The efforts of Carolyn Morris, who typed and retyped the various drafts, are especially appreciated.

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GLOSSARY OF TERMS

Acquisition Phases--The four distinct phases through which a weapon system progresses as a statement of need is converted into operational hardware (Conceptual, Validation, Development, and Production) (16:3-4).

Buying Office--The ASD activity which is charged with the responsibility for procuring a specified system(s) or subsystem(s). Unless specifically stated, this term will apply to all ASD program offices whether major or small. A common term, used in ASD, which is essentially the same as "Purchasing Office" as defined in the Defense Acquisition Regulation (DAR), formerly the Armed Services Procurement Regulation (ASPR).

Collocated--"A type of assignment whereby a person who, because of a functional or supportive skill, is placed with a user organization to meet a specific need. Collocated personnel are physically located in the user organization and are responsible through appropriate channels to the user organizational chief [2:2]."

Contractor-Furnished Equipment (CFE)--"Items acquired or manufactured directly by the contractor for use in the system or equipment under contract. CFE includes both mission equipment and support equipment [1:p.1-1]."

Dedicated--"A type of assignment whereby a person who, because of a functional skill, is assigned to support a specific program by giving that program first priority for a period of time. This individual is available to support other efforts when not needed on the assigned program. The assignment may involve remote support from a home office location and is primarily used to meet work surges or in a situation where an individual is not required full time on one program [2:1]."

Equipment--"A major subdivision of a weapon system or subsystem that performs a function impacting the operational capability and readiness of the weapon system/subsystem. It is grouped into two general categories, that is, mission equipment and support equipment. Equipment does not denote bit-part pieces or component elements that comprise an equipment entity. Management flexibility and the widely varying complexity and nature

of Air Force programs dictate that the term equipment be given only a general meaning. In the application of this regulation, the terms equipment, item, and unit have the same meaning [1:p.1-1]."

Functional Task List--A detailed list developed by ASD manufacturing staff personnel which identifies, by program phase, those manufacturing management tasks required to be accomplished by regulations. The list is used to assure consistency in determining required manpower levels within ASD SPOs (13).

Government-Furnished Equipment (GFE)--"Items in the possession of or acquired directly by the Government and subsequently delivered to or otherwise made available to the contractor for integration into the system or equipment. GFE includes both mission equipment and support equipment [1:p.1-1]."

Home Office--"The office within the home organization to which an individual is functionally assigned (as specified by SF 50, Notification of Personnel action or AF Form 2095), Assignment/Personnel Action [2:2]."

Home Organization--"The functional area deputy level organization (Comptroller, ASD/AC), Engineering (ASD/EN), and Procurement/Manufacturing (ASD/PM) [2:2]."

Major Program--A program in which cumulative anticipated expenditures are expected to exceed $75 million for research, development, test, and evaluation or $300 million for production (12:2).

Matrixing--"The concept of classifying and assigning skills by functional area and collocating/dedicating personnel with these skills to support program/project organizations [2:2]."

Mission Equipment (ME)--"Any item which is a functional part of a system or subsystem and is required to perform mission operations. It includes such items as missile launching mechanisms, engines, constant speed drives, munition pylons, command and control displays, radar sets, and aircraft radios [1:p.1-1]."

Product Division--The Air Force Systems Command Divisions which are responsible for the research, development, and procurement of major weapon systems (i.e., Aeronautical Systems Division (ASD), Electronic Systems Division (ESD), and Space and Missile Systems Organization (SAMSO)) (6:p.A2-1).

Senior Collocate--"The senior functional specialists operationally assigned in support of a Deputy and/or a Directorate level program/project [2:2]."

Statistical Type II Standard--"A standard based on validated statistical or historical data, or manpower allowances, and results in a statement of allowed manpower [14:p. 1-2]."

Support Equipment (SE)--"Includes all equipment required to perform the support function, except that which is an integral part of the mission equipment. It does not include any of the equipment required to perform mission operations functions. Support equipment should be interpreted as including tools, test equipment, automatic test equipment (ATE) (when ATE is accomplishing a support function), organizational, field and depot support equipment, and related computer programs and software [1:p.1-1]."

User Organization--"The organization to which an individual is collocated (operationally assigned) by the home office to provide a specific skill or support to this organization's program; for example, a System Program Office (SPO) or a deputy having purview over a number of SPOs [2:2]."

ABBREVIATIONS

ASD	Aeronautical Systems Division
CAS	Contract Administration Services
CFE	Contractor Furnished Equipment
DAR	Defense Acquisition Regulation
DSA	Descriptive Systems Approach
DSARC	Defense System Acquisition Review Council
ECP	Engineering Change Proposals
ESD	Electronic Systems Division
FMS	Foreign Military Sales
FSD	Full-Scale Development
GFE	Government Furnished Equipment
IOC	Initial Operational Capability
MAS	Man-hour Accounting System
ME	Manufacturing Engineering
MEP	Manpower Engineering Program
MET	Manpower Evaluation Team
MLR	Multiple Linear Regression
MM	Manufacturing Management
MM/PCR	Manufacturing Management/Production Capability Reviews
MOA	Memorandum of Agreement
PDP	Program Director Philosophy
PMRT	Program Management Responsibility Transfer

PRR	Production Readiness Reviews
PTMR	Program Technical Manufacturing Risk
PTMRF	Program Technical Manufacturing Risk Factor
RFP	Request for Proposal
RUC	Resource Utilization Committee
SAMSO	Space and Missile Systems Organization
SOW	Statement of Work
SPO	System Program Office
SPSS	Statistical Package for the Social Sciences
SR	Special Review
TMR	Technical Manufacturing Risk
UON	Urgency of Need
WDS	Weapon Delivery System

CHAPTER I

INTRODUCTION

Overview

This chapter is designed to introduce the reader to the subject of the study. The first step is to define the problem. Then, for readers not familiar with the subject area, this chapter also contains background information regarding the matrix management of manufacturing personnel assigned to the Aeronautical Systems Division (ASD). Concluding the chapter is a description of the objectives, research question, and research hypothesis of the study.

Problem Statement

Manufacturing personnel assigned to the buying divisions are responsible for analyzing contractors' manufacturing management proposals and for providing continuing analysis of the contractor's progress towards manufacturing and delivering the end item following contract award. These functions include analyses of manufacturing techniques, material and production control, make-or-buy decisions, schedules, and the impact of contract changes or manufacturing problems on the successful completion of the contractor's manufacturing function (7:pp.1-2 to 1-4). Within ASD, the Deputy for Procurement and Manufacturing,

operating in a matrix organization, is responsible for controlling and allocating all manufacturing personnel resources (AFSC 65XX, and General Schedule series 801/896/1150) assigned to the ASD buying offices (3:p.24-5).

Current regulatory direction requires annual reviews of the manufacturing manpower requirements to support each program office. From a management perspective, the current review process is deficient in that the reviews are time-consuming, subjective, and limited to the near term. In addition, it has not been determined that all relevant factors are considered in the reviews. Thus, the annual review process is inherently reactive and is of little value in projecting future requirements. Because the procurement and manufacturing staff has only limited resources, an improved method (in terms of usefulness, timeliness, and accuracy) for determining manufacturing personnel requirements is needed to concurrently reduce the time spent in the review process, and provide a more meaningful management tool. A method is required which can satisfy the regulatory requirements as well as meet the needs of aggregate manpower planning (19).

Background

The normal acquisition process of a major weapon system can generally be broken down into four distinct phases: conceptual, validation, full scale development, and

production (16:3-4). Divisions between the phases are represented by DOD decisions as to whether to continue the acquisition process or not. The decision is generally the output of the Defense System Acquisition Review Council (DSARC) (17:5-7). Figure 1 depicts the four phases of the system acquisition process and the appropriate DSARC milestones. However, this figure represents the ideal case and does not reflect deviations from the ideal; e.g., the A-10 system was subject to a DSARC IIIA decision for long lead time items followed by a DSARC IIIB for final system go-ahead. The various phases of the system acquisition process affect the role of the Air Force manufacturing personnel in both emphasis and magnitude.

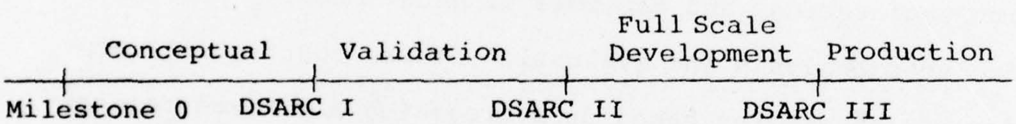

Fig. 1. Major System Acquisition Process

Role of Manufacturing Personnel

During the conceptual phase, the primary emphasis is on production feasibility. This requires an understanding of the current state-of-the-art in manufacturing techniques and processes as they relate to the system being manufactured. The program office's manufacturing representative is responsible for reviewing and analyzing the

proposed system to determine if the system can be built with current technology. He is also responsible for identifying technological deficiencies and for coordinating potential resolution of these deficiencies between Air Force laboratories and the contractor(s) (7:pp.A1-3,A1-5).

Production feasibility continues into the validation phase although the primary emphasis during the later stages of this phase shifts to producibility analyses. Producibility differs from feasibility in that the latter is concerned with technological practicability while the former is concerned with the most efficient means of producing the systems at the rates required to support Air Force needs. Producibility is also a function of manufacturing engineering, and the role of manufacturing personnel includes analysis and evaluation of the contractor's producibility studies based upon projected Air Force requirements; i.e., schedules and quantities.

Producibility starts in the latter stages of the conceptual phase, receives primary emphasis during the earlier stages of validation and continues throughout the other phases of the program. However, manufacturing management also plays a critical role during the middle to latter stages of validation. Overall program office manufacturing strategies are developed during this phase: contractual requirements are developed for the proposed statement of work (SOW), tentative program milestones are developed,

special reviews and evaluation requirements are tentatively identified, and the basic manufacturing organization within the program office is established (7:pp.A1-5,A1-6; 4:Ch.3).

The Full-Scale Development (FSD) phase begins with DSARC II approval and source selection. During this phase, primary emphasis is placed upon analysis and evaluation of the contractor's production plan, resolution of manufacturing risk, engineering change proposal evaluation, and special reviews of the prime and major subcontractors to determine their progress towards a readiness posture to produce the end-item at an acceptable level of risk. The roles of the contractor and government in providing support equipment and subsystem/components are also refined during this phase, and planning is done to achieve respective tasks (7:pp.A1-6,A1-7; 4:Ch.4).

As can be seen, the groundwork to manufacture the hardware has been established throughout the phases leading up to the production phase. The production phase is primarily concerned with resolution of manufacturing problems encountered during early production, coordinating government and contractor activities, evaluating the impacts of engineering change proposals, and monitoring and ensuring contractual schedules (7:pp.A1-7,A1-8; 4:Ch.5).

Determination of Manpower Requirements

Prior to October 1976, determination of individual program manpower requirements to support the above functions was the responsibility of the program office director. However, in October 1976, a matrix management concept was applied to the procurement and manufacturing functions at ASD, and the responsibility for determining manpower requirements to accomplish these functions was changed. The ASD Deputy for Procurement and Manufacturing (ASD/PM) was given the responsibility for determining the manpower levels required to support the manufacturing and procurement functions within each buying office (3:p.24-7).

According to ASD Regulation 30-2, Management of Collocated/Dedicated Personnel, the primary objectives of the matrix organization are to:

a. Prescribe a framework for providing necessary functional support skills to the program offices within total manpower capability.
b. Provide flexibility in making functional personnel adjustments to meet workload fluctuations, and make the most effective use of available personnel skills.
c. Ensure that the quantity and mix of functional skills are balanced between and within the designated program offices to best meet program requirements.
d. Ensure that functional personnel are adequately trained within a specialty to provide the most advanced concepts in functional skills to the program managers in the performance of their management responsibilities.
e. Establish responsibility under a single focal point within the designated career field for the effective

management of career development of functional specialists.

f. Establish a forum for the crossfeed of innovative techniques, utilization of uniform procedures, applications of lessons learned, and the development of new skills [2:1-2].

Additionally, this regulation requires that the matrixed staff agencies conduct an annual review of the quantity and skill levels of personnel required to support their functions within each buying office (2:1-3).

These changes represent a significant departure from practices for determining functional manpower levels required within ASD. Beginning in 1970, the Vice Commander created the ASD Resource Utilization Committee (RUC) charging it with the responsibility for ensuring that all ASD buying office manpower requests were valid. The RUC also was given responsibility for authorizing buying offices to hire individuals to fill approved positions (28).

Before the matrix concept was implemented, each buying office was responsible for initially determining its manpower requirements and submitting a manpower proposal to the RUC for approval. This practice also applied to all staff offices. Once the manpower proposal was received by the RUC, the Air Force Systems Command Manpower Evaluation Team (MET-30) was charged with the responsibility for assessing the management effectiveness (i.e., clerical support, supervision, and organization) of each manpower proposal. MET-30 would then advise the RUC of its

findings and, in general, serve in an advisory capacity to the RUC (28).

Under the present matrix concept, MET-30 still acts as the manpower advisor to the RUC. However, the RUC no longer has final authority to approve manpower proposals nor to authorize new hires. The RUC's role is now an advisory one to the ASD Commander with whom final authority lies. The buying offices are still responsible for submitting manpower requests to the RUC, but only non-matrixed functional requirements are directly recommended to the Commander. Matrixed manpower requirements must now be filled by the responsible functional staff agency from within their existing personnel resources. If the staff determines a need for additional manpower to accomplish assigned tasks, the staff must submit a manpower proposal to the RUC which may or may not be recommended to the Commander. Therefore, both the identification of manpower needs and the fulfillment of those needs for all ASD buying offices are now responsibilities of the applicable staff agency (28).

Consequently, the matrixed staffs now have the responsibility for coordinating their functional manpower requirements with the buying offices. The staffs also have the responsibility for allocating personnel to ensure that their respective functional tasks are accomplished within each ASD buying office (13; 28).

The ASD manufacturing staff has made some progress in developing objective approaches to accurately quantify manpower levels required to support the functional tasks within each buying office. To this end, a functional task list, based on regulatory documents, has been developed for each phase of the acquisition process. This list details the manufacturing management tasks to be accomplished by each individual program office. As a supplement to the functional task list, the manufacturing staff has also developed a questionnaire to solicit, from each buying office, data that the staff deems necessary to understand the magnitude of each functional task within the buying offices. Examples of such data include the number of contracts, dollars involved, phase of the program, number of prime contractors and subcontractors, technical and management complexities, type of end items procured, and other pertinent factors. Within the staff, selected individuals are identified as focal points of contact with specific buying offices to enhance an understanding of the peculiar organizational characteristics of each office (19; 20).

During each annual manpower review, the staff forwards the above-mentioned questionnaire and functional task list to the senior manufacturing collocate within each buying office. The senior collocate answers the questionnaire and identifies the expected frequency of each functional task. Since each office responds to the same questionnaire

and functional task list, a consistent basis is provided for the staff to make initial estimates of required manpower levels (13; 19; 20).

The staff reviews the questionnaires to identify critical program characteristics and peculiarities, and the buying office focal point makes his inputs as to peculiar organizational characteristics which could affect manning levels. Senior personnel in the staff then assess the manpower requirements of each buying office based upon their experience, responses from the senior collocate, and inputs from the staff focal points (13; 20).

In determining functional matrix manpower requirements as described above, the manufacturing staff has assumed some of the responsibilities previously held by MET-30 (28). However, MET-30 acknowledges that technical functions such as manufacturing in the research and development environment are not readily amenable to developing standard hours for across-the-board functional tasks. Therefore, the experience and insight concerning the ASD environment which is held by key individuals in the staff provides more validity to projected manpower levels than simply using predetermined man-hour standards (13; 28).

Both MET-30 and the ASD manufacturing staff acknowledge that current manpower determination procedures are subjective in many aspects. However, both organizations assert that present practices do provide a basis for

comparing the relative magnitude of manning requirements among ASD buying offices (19; 28).

Continuing efforts are being made within the manufacturing staff to refine present techniques and to find more objective methods to predict manpower requirements for each buying office. An example of these efforts is the refinement of man-hour reporting categories for manufacturing tasks which are inputs to the ASD man-hour accounting system (13; 20).

The man-hour accounting system (MAS) is a computerized system which tabulates man-hour expenditures for all ASD personnel according to predetermined codes that are assigned to functional tasks. The system was initially created, in 1970, as a management tool to identify organizations and functional tasks in which overtime was being extensively used to accomplish program objectives. Assuming the inputs are accurate, the system can also be used to cross-check hours expended on specific functional responsibilities within the buying office. This information can be useful when additional manpower authorizations are requested (28).

The manufacturing staff is currently expanding and defining new functional task codes which correspond to the previously mentioned functional task list used in assessing manpower requirements in the buying offices. Staff personnel feel that this effort will provide more meaningful

man-hour reporting data which can be used to correlate critical program requirements with man-hours expended (13; 20).

HQ AFSC has also expended considerable effort in developing predictive aggregate manpower models for AFSC buying divisions. This aggregate model is, to a large degree, based upon general, cumulative buying office functional tasks within each buying division (8).

Although it still requires further refinement, MET-30 personnel expect that the aggregate model will be useful in predicting divisional manpower requirements in the future. Because it is macro in nature, the model does not provide sufficient information to determine optimum manpower levels to meet functional tasks requirements at the buying office level (28). Therefore, both MET-30 and the manufacturing staff are seeking improved methods or techniques to determine and predict optimal manpower requirements at the functional task level.

Objectives

The objectives of this study are:

1. To analyze the current ASD manufacturing matrix organization and to identify the basic functions which determine manufacturing manpower requirements to support ASD fighter programs.

2. To identify the internal and external variables which interact with the basic functions to determine specific fighter program manufacturing manpower requirements.

3. To develop a methodology, utilizing the basic functions and the internal and external variables, that can be used to predict necessary manufacturing manpower levels for ASD fighter programs in both the near and long term.

Research Question and Hypothesis

In order to accomplish the objectives, the following research question and hypothesis are addressed in this study:

1. Can an analysis of the current manufacturing matrix organizational responsibilities and ASD manpower policies provide sufficient insight into the manpower structure to identify the basic functions and the internal and external variables which determine manufacturing manpower requirements to support ASD fighter programs?

2. Manufacturing manpower requirements can be predicted by analyzing the effects of the interaction of the basic functions and the internal and external variables.

Organization of the Study

The following chapter describes the methodology that guided the research effort. Chapter III addresses the detailed analysis of the system relationships, while

Chapter IV contains a comparative analysis of the model predictions versus actual manpower authorizations. Chapter V contains the findings of the study. Conclusions and recommendations are stated in Chapter VI.

CHAPTER II

METHODOLOGY

Overview

This chapter describes the methodology employed in the study. In so doing, it addresses the sampling plan, data collection plan, operational definition of variables, classification of variables, design to test the research hypothesis, and the applicable assumptions and limitations of the effort.

Sampling Plan

The universe of interest includes all major ASD acquisition programs. The population of interest is the manufacturing personnel requirements to support the major fighter programs at ASD. However, due to time restrictions and the complexities in obtaining relevant manpower data, a census of all past and present major fighter programs was not practical (9). Therefore, a stratified sample was selected that included three current fighter programs: A-10, F-15, and F-16.

The variables used in analyzing manufacturing manpower requirements are considered applicable to all fighter programs. Data were collected for each of the programs from the validation phase through to the production phase.

Program and subsystem complexities ranged from state-of-the-art design to highly advanced development. The complexity of each program was different from the other programs and reflected numerous factors such as the degree of involvement in managing Government Furnished Equipment (GFE) and Foreign Military Sales (FMS). Therefore, in the aggregate, these programs are assumed to be representative of future fighter programs at ASD.

Findings associated with this study should be applicable to all future major fighter programs at ASD that follow the existing DOD standard acquisition process. While not directly applicable, the relative importance of program variables may provide insight in predicting the manpower levels required to perform the manufacturing functions for ASD missile and bomber programs. This hypothesis is based on the fact that the task structure of all major programs is very similar and varies only in relative emphasis.

Data Collection Plan

From the literature review, previous studies, and discussions with the directors of manufacturing in the A-10, F-16, and F-15 programs, and with the ASD staff, certain key manufacturing functions were identified as being required during the acquisition life cycle of all major programs. These functions are manufacturing engineering,

manufacturing management, special reviews, and government furnished equipment (GFE) management.

Manufacturing engineering deals primarily with the manufacturing technological requirements. Manufacturing management is primarily concerned with areas such as manufacturing planning, source selection, schedules, coordination between the System Program Office (SPO) and contractor, and daily operations or problems. Special reviews are the specific activities required to ensure that the contractor is in a posture to implement his manufacturing plans and processes. The government furnished equipment management function represents the effort expended in identifying, scheduling, and ensuring delivery of the items or subsystems that are provided by the government to support the contractor's manufacturing operations.

In addition to the above basic functions, certain key variables were identified as being potentially significant in modifying the manufacturing manpower requirements as established by the basic functions. Consequently, the following variables were selected for analysis of potential value in predicting manufacturing manpower requirements (5:28; 12; 13; 22; 25; 27).

1. Manufacturing manpower is the dependent variable in this study. Manpower authorizations beginning in 1969 through July 1978 were collected. These data were available through the records kept by MET-30, the ASD

Historical Office, individual SPOs and the manufacturing staff office. An initial effort attempted to extract the data from the ASD Man-Hour Accounting System (MAS). However, it was found to be impossible to track man-hours expended in accomplishing manufacturing tasks because of errors in reporting and changes to the reporting procedures over the period covered by the research. Authorized manning levels by program were used to determine historical relationships between past manning levels and past program parameters (9; 13).

2. Technical manufacturing risk, as defined within this study, is the cumulative effects of major subsystems design complexity (i.e., airframe, engine, avionics and electronics, and weapon delivery systems). In other words, are the subsystems within the state-of-the-art or do they involve designs requiring advanced manufacturing techniques? The impact of design and subsystem development on manufacturing requirements was assessed and appropriate values assigned to each major subsystem of the program at the beginning of program validation. Interviews with program office representatives and the manufacturing staff were the sources used to develop this factor.

3. A variable called Program Director Philosophy (PDP), represents the interpretation by the Program Director of the regulatory requirements. The PDP has a greater impact upon program office manpower allocations than upon

actual manpower requirements. However, PDP has the potential to directly affect manpower requirements to accomplish government furnished equipment activities.

4. Urgency of need (UON) does not change the actual tasks to be accomplished but rather their rate of accomplishment. As such, manpower authorizations will vary between extended or compressed programs. The UON variable is the ratio of program development time compared to a standard.

5. A variable identified as Contractor Capability was included in an attempt to identify the variations among the contractors and how these variations affect manufacturing personnel requirements. The value of this variable was determined from such factors as the contractor's experience, capability, and the time since his last similar contract.

6. Cognizant Contract Administration Services (CAS) activity support is another external variable which can have significant impact on manufacturing personnel requirements. This variable is an interval value based on the size of the CAS, recent contracts (similarity and magnitude), and the Memorandum of Agreement (MOA) between the CAS and the buying office.

7. The effect of Foreign Military Sales (FMS) was included as an interval scaled factor for each program based upon such factors as the number of foreign countries purchasing the respective system, the number of systems

procured, and time of procurement. This information was available from official program documents.

8. The program acquisition phase was initially included as a separate variable since it has a direct bearing on the type of manufacturing management effort required by the program office at specific points in time. However, this variable was found to have no significance in itself but was inherent in all the other factors and/or variables.

9. Co-production in this study is defined as direct involvement with foreign industry in manufacturing the systems or subsystems for which the program office has responsibility. This information was also readily available in official program documents (22).

10. The existence of Government Furnished Equipment (GFE) was recognized as a variable requiring manufacturing management effort. The number of GFE items and associated costs suggested a means to measure the effects of GFE on total manufacturing manpower requirements. However, after a detailed analysis, GFE was deleted as a variable and became a basic function required in all programs. A detailed discussion of this factor is contained in Chapter III.

11. Subsystem integration is the contractually specified role that a program office performs in integrating the efforts of the various contractors associated with the program.

Since the data collection and analysis was an iterative process, variables were added and deleted depending on their appropriateness for explaining the manufacturing manpower requirements for a major SPO. Additional variables were added if they logically exhibited a potential for increasing the efficiency in explaining variations. The inclusion or deletion of a variable was determined by a trade-off between cost to acquire data and the contribution of that data to increasing the efficiency of predicting manpower requirements. That is, a trade-off was made among data availability, time to gather the data, data processing costs, ease of gathering the data, and the marginal increase in the predictive efficiency. The variables were grouped and classified as shown in Table 1.

Design to Test Research Question and Hypothesis

Several techniques for analysis were considered during the data gathering phase. This variation was deemed necessary since new variables and relationships became evident as the study progressed. Because the intent of the research effort was to develop a useful management tool that could be employed by the ASD manufacturing staff, each potential design effort was evaluated as to its practicability in determining manufacturing manpower requirements for both existing and new programs. Therefore, the design

TABLE 1

CLASSIFICATION OF VARIABLES

Variable	Data Level	Data Value
Manufacturing Manpower	Interval or Better	Discrete, Infinite
Technical Manufacturing Risk	Interval	Discrete, Multiple
Program Director Philosophy	Ordinal	Discrete, Limited
Urgency of Need	Ordinal	Discrete, Limited
Contractor Capability	Interval	Discrete, Multiple
Cognizant Contract Administration Services	Interval	Discrete, Multiple
Foreign Military Sales	Interval	Discrete, Limited
Program Acquisition Phase	Interval	Discrete, Limited
Co-production Effort	Nominal	Discrete, Dichotomous
Government Furnished Equipment	Interval	Discrete, Multiple
Subsystem Integration	Interval	Discrete, Limited

to test the research question and hypothesis was not restricted to any one method, but evolved from examining various methods. These methods are discussed in the next section of this chapter and are provided as background to the reader.

In order to answer the research question and test the hypothesis, a model was developed. Basic manufacturing functions employed in the model were extracted from DOD and AF regulatory documents. The variables (internal and external) used in the model were identified through analyses of ASD manpower policies, the organizational responsibilities within the ASD manufacturing matrix, and through interviews and discussions with senior manufacturing personnel within the ASD staff and program offices. The model as developed will be tested and validated through its ability to explain the actual manpower levels experienced by the F-15, F-16, and A-10 programs.

Additionally, validation of the model will (1) confirm that the basic functions, and the internal and external variables, which determine ASD fighter program manufacturing manpower requirements, have been identified and, thus, answer the research question, and (2) support the research hypothesis that manufacturing manpower requirements can be predicted by analyzing the effects of the interaction of the functions and variables.

Initial Test Structure

A stepwise Multiple Linear Regression (MLR) program from the Statistical Package for the Social Sciences (SPSS) was first considered as the computer tool for the statistical analysis (23:320-367). This technique was chosen as the initial modeling approach since it was successfully used to predict aggregate System Program Office (SPO) manpower requirements (8:60-63) and since the SPSS package is a readily available computer program. The SPSS package permits testing and analysis of regression efficiency, residual variance, multicollinearity, and time-dependency among variables. Details concerning the initial plan, criteria, and application are contained in Appendix A.

Deficiencies in the Initial Test Structure

Inherently, as the name implies, Multiple Linear Regression is most appropriate for variables displaying linear relationships or which can be transformed into a virtual linear appearance. When the variable relationships are not linear, non-linear coding is a common technique to meet the requirements of MLR. Also, before the results of MLR can be considered valid, the sample data must meet certain statistical criteria (24:544-545).

In this research effort, three possible MLR applications were considered: (1) perform a regression at a fixed point in time common to all programs (i.e., FSD),

(2) perform a series of regressions at specific points in time common to all programs and dispersed throughout the life cycle of the program, or (3) perform a regression with time as a variable.

Single Regression

In the first case, it was very questionable whether sufficient sample data were available upon which to make any significant statistical conclusions from the output of the SPSS program. Another deficiency in this approach is its failure to provide any information as to the manning level at any time other than the regression time. In the AFSC model, empirical data were collected as to the various average manning levels within the life cycle of the program. Then, knowing the manning at the regression time (full-scale development), manning at any other time was computed as a percentage of the FSD manpower level. This adjustment assumes that the historical empirical data accurately captured the essence of the manning function.

While this technique may be appropriate in examining aggregates, it was not considered appropriate for a specific skill where the various driving factors do not maintain a constant relative relationship or magnitude throughout the life cycle of a program. Based on interviews with key personnel, both in the staff and the line organizations, it was determined that the various factors

were non-linear and definitely not in fixed proportions as a function of time.

Multiple Regression

This method overcomes the limitation of the single regression approach by performing multiple regressions at selected points in time. However, this method could easily become too unwieldy as a practical management tool because of the number of regressions required. Performing five regressions between each decision point (DSARC reviews, IOC, and PMRT) would have resulted in at least twenty individual regressions with twenty unique equations. Also, the sampling problem of insufficient data was still present in this method. Again, like the first method, this approach assumes that past manning levels were correct and that the past is an accurate predictor of the future.

Regression Including Time

This alternative, and the one with which the most effort was placed, involved a regression with time as one of the variables. However, to be meaningful, this method requires that the non-linear behavior of the individual variables be transposed into virtual linear relationships or equations. The problem of handling this translation can be appreciated by a review of the technique of MLR.

As noted from the AFSC study (8:41), SPO manning peaks at some instance in time and has a shape

characteristic of a normal curve. An analysis of the data indicated that the manufacturing manning also follows a similar pattern within the aggregate SPO curve. Since SPSS attempts to pass an "m" dimension linear surface (linear surface with as many dimensions "m" as there are variables) through the data points using a method of least squares, the statistical output decreases in value as the non-linearity of the variable relationships increase. A simple explanation in two dimensions is depicted in Figure 2. Note the poor fit of the regression line to a function similar to the normal curve, Figure 2(b).

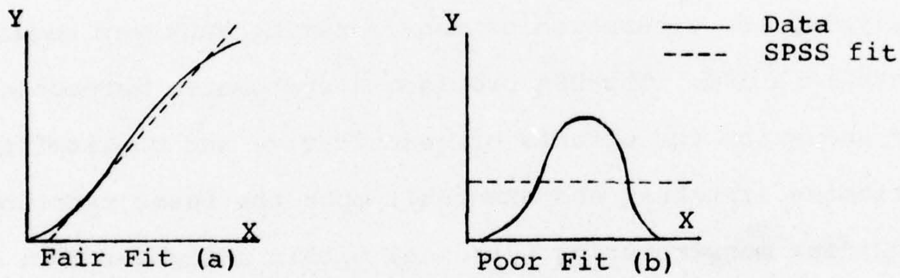

Fig. 2. Simple Linear Regression Fit

Because many of the variables exhibited complex shapes, a method of linearization was required before this option could have been made viable. But again, there was the question of benefits-to-cost trade-offs. This method could perhaps be made workable, but the complexity of the variable equations would preclude the manager from readily

updating the model as environmental factors changed. Changes would be as complex as the original development effort.

Descriptive Systems Approach (DSA)

The considerable effort expended in studying the various multiple linear regression techniques provided an understanding of the structure of the ASD manpower system and led to the descriptive systems approach. This approach was developed by the researchers to combine both hard and soft data into a methodology for projecting future requirements. Essentially, DSA employs the systems approach for analyzing the generation of manufacturing manpower requirements in a SPO. The DSA provides a systematic methodology for analyzing the effects of quantitative and qualitative variables (internal and external) upon the basic functions requiring manufacturing personnel within a fighter SPO.

When using the DSA, the first task is to identify the overall system in which the subsystem of interest lies. Once the overall system is identified, one can begin to analyze the variables and functions that have an impact on the subsystem of interest. In this study, the overall system was the major system acquisition process and the subsystem was manufacturing manpower requirements.

Although the DSA may lack in rigor, its power of application is in the level of understanding it provides

the user. Rather than generating finite numbers, the DSA provides a planning methodology for arriving at reasonable future predictions of manufacturing manpower requirements.

Because the DSA is very similar to the techniques used in Systems Dynamics (18:1-6), an introduction to Systems Dynamics and its application to the determination of manufacturing manpower requirements is contained in Appendix B. The appendix is provided to guide further research efforts which may investigate the possibility of applying a computer simulation program to the manufacturing manpower requirements process.

The premise of this study is that there are certain manufacturing functions that must be accomplished in all major ASD weapon system acquisitions. The level and schedule of these functions are affected by the interaction of numerous variables. For example, the function of manufacturing engineering is directly related to the level of technical manufacturing risk. As risk increases, so does the level of manufacturing engineering effort. Conversely, the function of government furnished equipment management appears to be inversely related to technical manufacturing risk. As the risk is reduced, more and more items are identified as potential candidates to be managed as GFE.

Based on the analysis of the manufacturing manpower requirements process, it was postulated that there are certain functions that must be accomplished in any major ASD

effort and that a composite of these requirements establishes a baseline under certain specified conditions. In addition, this baseline is affected by key variables (program specific) in three ways: shifts in amplitude, shifts in phase, or a combination of amplitude and phase shifts. Therefore, once the baseline curve is generated, management can modify the curve with program specific requirements, and thus derive a projection of future manpower requirements. Also, this model approach is readily adaptable to refinements as the environmental factors change. The basic advantages of this approach are that it readily exposes the interactions of the variables and permits the manager to structure his manpower on the basis of visible factors.

Assumptions and Limitations

The validity of any model in predicting future outcomes depends upon the basic assumptions of the model and its inherent limitations. Therefore, the following assumptions and limitations are provided as information in determining the applicability of this model to specific programs.

Assumptions

1. Reliable forecasts of future manpower requirements can be obtained through study of historical relationships between manpower levels and key program variables (5:44).

2. The variables under consideration are applicable to all ASD fighter programs.

3. Valid data relative to each variable are available through analysis of official program documentation.

4. Data pertaining to ASD manpower authorizations, if in error, are uniformly inaccurate among the sampled programs (9; 13).

Limitations

1. The model is applicable only to major ASD fighter acquisition programs. However, the interaction of the variables discussed in Chapter III may have possible applicability in assessing manpower requirements of other types of programs; i.e., missile and bomber.

2. The model is applicable only to programs that evolve through the normal system acquisition process. It does not consider radical changes in enemy threats, although it does reflect the urgency of need for development of a program to a standard.

Summary

The primary population of interest is the manufacturing manpower authorizations required to support major ASD fighter programs. Three current ASD programs were selected as a representative sample of future major ASD fighter programs. Key program functions and variables

which exhibit general applicability and variability to all programs were chosen to explain the behavior of the manpower structure. A model was developed to show the relationships among these functions and variables and manufacturing manpower requirements. The validity of the model is restricted by the validity of its application. The model is currently limited to major ASD fighter programs which follow the normal DOD system acquisition process. However, because the structure of the model is basic to any major ASD acquisition effort, the model may also be applicable to missile and bomber programs.

CHAPTER III

ANALYSIS OF SYSTEM RELATIONSHIPS

Overview

This chapter contains the analyses of numerous personal interviews, applicable publications, and historical manpower data. From these analyses, it appears that there are three factors which collectively influence the determination of the manufacturing manning requirements in the major fighter program offices. These factors are: (1) the basic functions (Manufacturing Engineering, Manufacturing Management, Special Reviews, and Government Furnished Equipment Management) which permeate all major programs; (2) certain key internal program variables such as technical manufacturing risk, co-production, subsystem integration, and program director's philosophy; and (3) certain external variables not within the direct control of the program manager such as urgency of need, contractor capability, CAS manning support, and FMS.

The next section of this chapter addresses the analysis of the basic functions which are established by regulations and are the genesis of manufacturing manpower requirements. Subsequent sections address the influence of internal and external variables to the program office

which affect the magnitude of the manufacturing manpower requirements to accomplish the basic functions. The chapter concludes with the development of a baseline curve which depicts the manufacturing manpower required by the interaction of the variables and basic functions.

Basic Functions

The general manufacturing personnel manning trend shown in Figure 3 is a composite of the four basic functional requirements: manufacturing engineering, manufacturing management, special reviews, and government furnished equipment. As is evident from the curve, manning requirements rise significantly during the latter stages of the validation phase and peak during FSD. After DSARC III (production authorization) the manning requirement begins to diminish but not significantly until after initial production problems have been resolved. Because of Engineering Change Proposals (ECPs) and GFE, a minimal level of manning continues through to program management responsibility transfer (PMRT).

Manufacturing Engineering

Manufacturing engineering is primarily concerned with production feasibility, producibility, and the evaluation of ECPs. Production feasibility is the determination of whether an item can be manufactured within existing technological capabilities. Producibility analyses seek

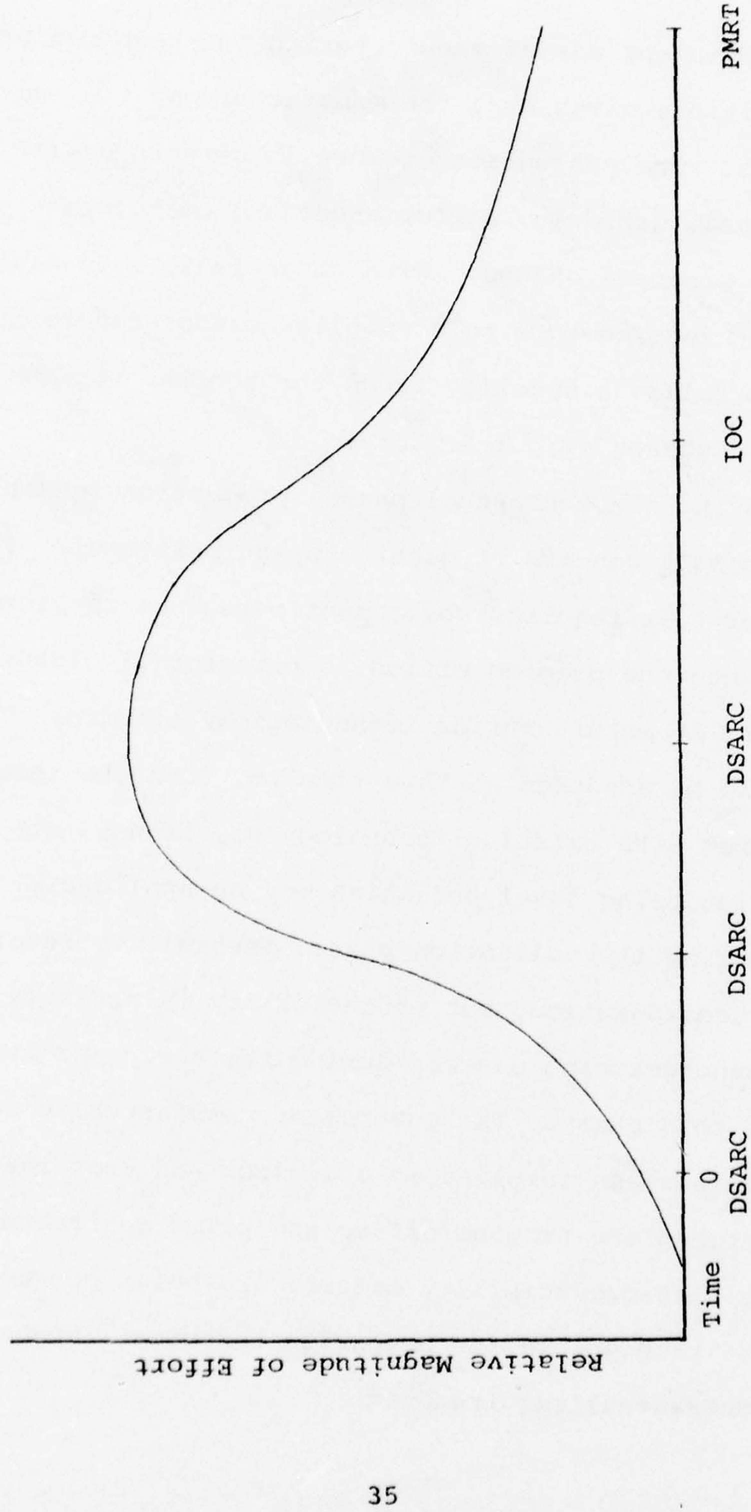

Fig. 3. Composite Trend Curve

the most efficient way of manufacturing the required program quantities, given that the manufacture of the end-item is feasible. The evaluation of ECPs is concerned with the technological, schedule, performance, and cost impact of making the proposed change. With these factors in mind, the manning requirements to accomplish associated tasks can be seen to follow a specific trend through the various acquisition phases (7:p.1-5; 15:2).

During the conceptual phase, production feasibility is the dominant concern of manufacturing personnel. This function or task requires government personnel to provide liaison among the program office, contractor(s), laboratories, and AF manufacturing technological efforts. The question to be answered at this time is, "Can the item be manufactured with existing technology or, if not, are new technologies being developed which may be applicable?"

During the validation phase, feasibility remains a strong consideration, but producibility is normally the primary manufacturing concern during the early and middle stages of this phase. The government manufacturing representative is again involved in a liaison and coordination effort between the program office and prime contractor(s) to ensure that producibility efforts are being pursued. He is also responsible for preparing technical inputs for future contractual requirements.

Producibility continues to be the primary concern of the manufacturing engineer during the FSD phase. But, his concern is now also focused upon the implementation of the technical manufacturing plans decided upon during the validation/demonstration phase. ECPs also begin to play a major role in the manufacturing engineering function during this phase since proposals must be evaluated in terms of feasibility, producibility, cost, and schedule impacts.

The manufacturing engineering effort tends to decrease during the later stages of FSD and in the production phase. During the production phase, the primary emphasis consists of evaluating the effects of ECPs, since previous manufacturing plans have been implemented.

Specific manpower requirements to accomplish the manufacturing engineering function will vary depending upon program characteristics such as: number of high risk subsystems, number of contractors, proposed duration of system development, and urgency of need. However, the general baseline trend for any program manufacturing engineering personnel requirements is shown in Figure 4.

Manufacturing Management

The second manufacturing function that permeates all major acquisition programs is manufacturing management. This function is the heart of the program office and contractor interface. It is the manufacturing management

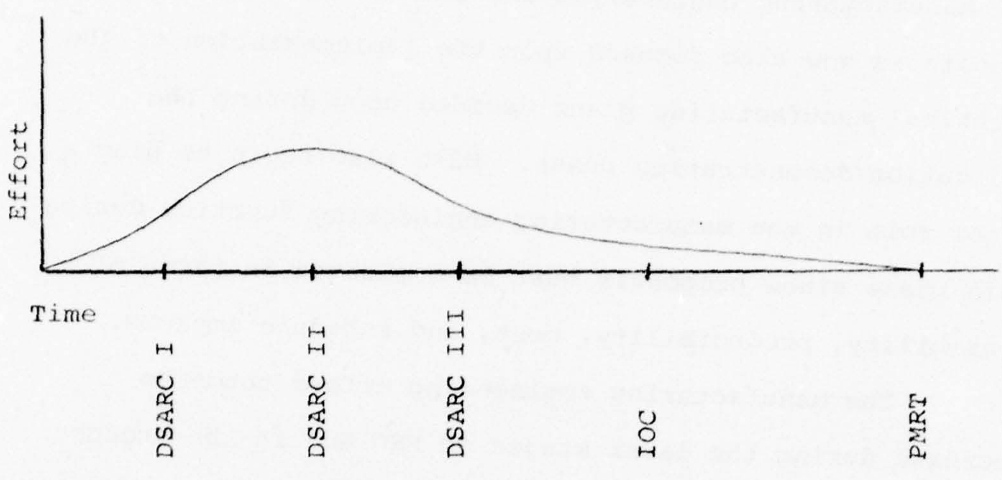

Fig. 4. Manufacturing Engineering Trend Curve

element that develops the overall program manufacturing strategies, develops complete manufacturing contractual requirements, and ensures the implementation of specific management systems and production plans at the prime contractor(s) and major subcontractor(s) facilities (15:2-3; 7:Atch.1).

As in manufacturing engineering, the technical manufacturing risk (TMR) is a dominant variable in determining the manning requirements. Co-production and the integrative roles appear to be additive factors. However, to compute a general baseline curve, co-production and the integrative role were set equal to zero. The effect of these two factors can be added to the baseline curve as appropriate.

Figure 5 depicts the general manning trend to support the manufacturing management function throughout the system life cycle. As depicted, manufacturing management becomes a significant factor during the middle and later stages of the validation phase. Prior to this time, the primary emphasis has been given to production feasibility and producibility. As the producibility of the system is verified as a valid system's concept, production plans are further refined and the tasking evolves more towards a management role. During the later stages of the validation phase, the tentative program office structure is developed, inputs are made to the statement of work (SOW) and request for proposals (RFP), and, most importantly, the overall *manufacturing management strategy* is developed at this time.

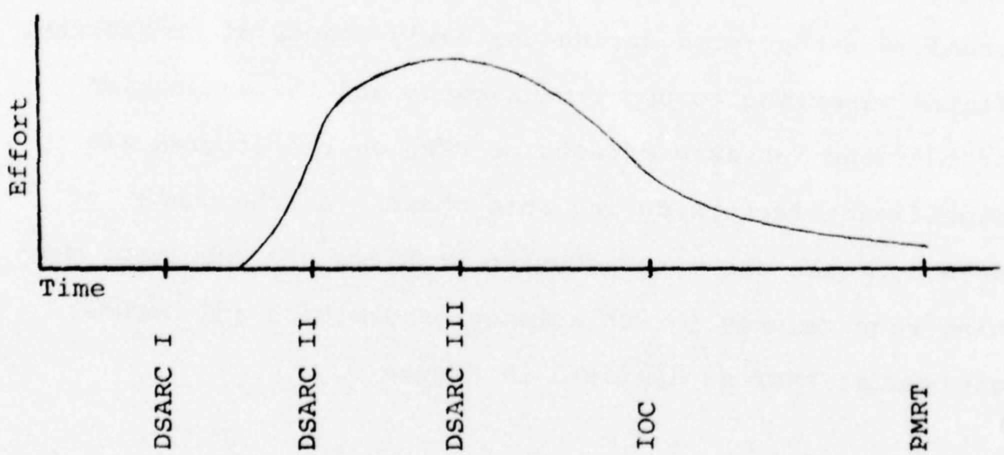

Fig. 5. Manufacturing Management Trend Curve (Effects of co-production and subsystem integration not included.)

The FSD phase requires manufacturing management to implement the overall strategy developed in prior phases. The primary roles of manufacturing management during FSD are: (1) coordinating government and contractor activities, (2) collection and analysis of data concerning the overall manufacturing status of the prime contractor(s) and the major subcontractor(s), (3) resolving manufacturing problems required to implement the contractor(s) manufacturing plans, (4) providing the interface between the contractor(s) and upper military echelons, and (5) ensuring that the contractor(s) has reduced manufacturing risk to an acceptable level for production release prior to DSARC III.

Subsequent to DSARC III and the decision to proceed into the production phase, manufacturing management is primarily concerned with the resolution of manufacturing problems encountered during the early stages of production. Status reporting to upper management and the evaluation of cost and schedule effects of ECPs on the program are significant factors during this phase. As the number of ECPs decrease and manufacturing problems are resolved, manning requirements for this function diminish and become minimal at PMRT as depicted in Figure 5.

Special Reviews

The third function that is common to all major programs is the conduct of special reviews which are required

by regulatory documents (15:2-3; 7:Ch.7). These reviews include such efforts as Manufacturing Management/Production Capability Reviews (MM/PCR), and Production Readiness Reviews (PRRs). Other reviews such as selected capacity/capability reviews may be conducted as required by the program director (13).

Manufacturing Management/Production Capability Reviews should be conducted concurrently with the source selection effort for the FSD contract award. Production Readiness Reviews should be completed prior to DSARC III. Planning for the MM/PCR should be accomplished prior to FSD source selection, and planning for PRRs should be initiated shortly thereafter.

Manning to accomplish these reviews is dictated by the technical risks, number of major subsystems, planned time for the FSD phase, the number of prime contractor(s) and major subcontractor(s), contractor capability, and CAS support. Again, absolute manning requirements are not universally applicable, but requirements do follow the trend shown in Figure 6.

During the production phase, the major emphasis of special reviews is follow-up on open items from the DSARC III review. Although requirements for these actions diminish rapidly after the initial production contracts,

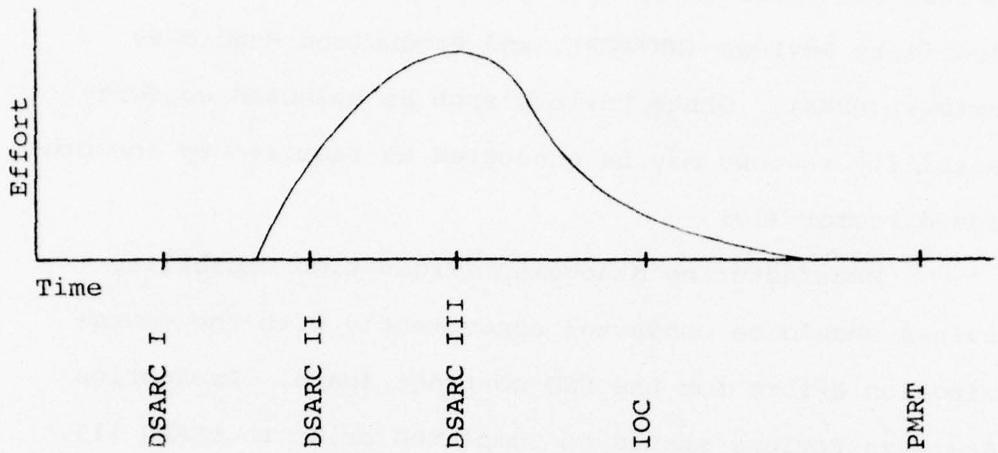

Fig. 6. Special Reviews Trend Curve

some effort is required for continuing reviews to determine the manufacturing cost/schedule impacts of production rate changes, ECPs, and major modifications.

Government Furnished Equipment (GFE) Management

The last function common to all major programs involves GFE. Government furnished equipment includes both mission equipment and support equipment in the possession of or acquired directly by the Government and subsequently provided to the contractor for integration into the system or subsystem (1:p.1-1). This function requires (1) initial identification of potential GFE, (2) establishment of GFE requirements and schedules to support the contractor's

manufacturing plan, (3) follow-up activities to ensure timely delivery of the items, and (4) continuous monitoring of the program for additional items that can be provided as GFE at a reduced cost to the Government (7:p.3-1).

Personnel requirements to accomplish this function generally follow the trend curve shown in Figure 7. Manpower requirements are lowest during the conceptual and early validation phases as the system(s) designs are being formulated. Manpower requirements begin to increase during the later validation stages due to the request for proposal (RFP) and statement of work (SOW) preparation, and organizing for FSD Source Selection (SS). The spikes in the curve reflect additional workloads generated by FSD source selection and the evaluation of the proposed production contract. The continuing effort shown from FSD source selection to DSARC III is required to schedule, coordinate, and monitor FSD GFE deliveries.

The increased manpower requirement for the production phase over FSD requirements can be explained by: (1) increased stability of design as the program matures, which increases the number of potential GFE items; and (2) increased coordination and schedule monitoring efforts to ensure that GFE is provided to the contractor on time and in the correct quantities and condition to support the contractor's manufacturing operations (7:p.5-1; 11; 13).

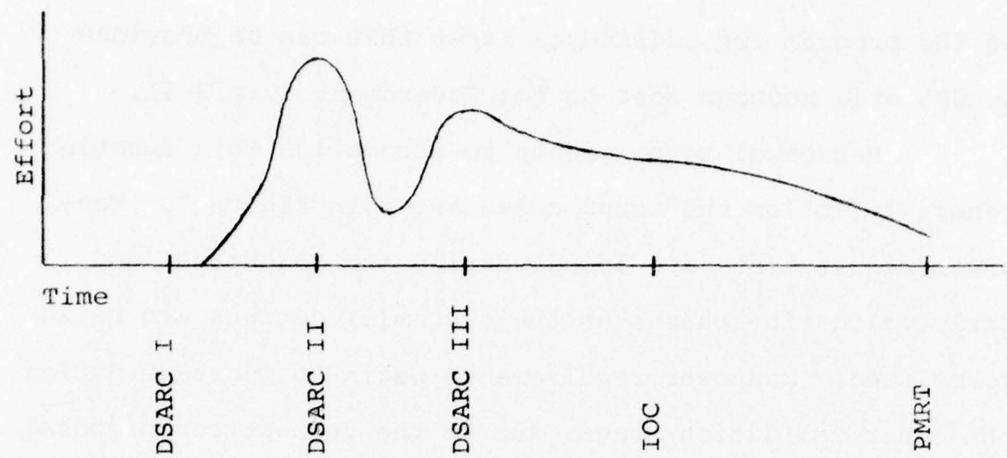

Fig. 7. Government Furnished Equipment Trend Curve

The relative magnitude of the program office GFE management involvement depends upon five key factors: (1) the design amenability to use existing systems/subsystems, (2) design stability, (3) the program management strategy relative to GFE versus contractor furnished equipment (CFE), (4) co-production, and (5) FMS (11; 13).

The first three factors affect the number of items provided as GFE and establish the basic level of effort. Co-production increases the level of effort by creating additional delivery destinations and schedule requirements. Foreign Military Sales (FMS) essentially creates duplicative funding, purchase requests, scheduling, and monitoring activities for each procuring country (11; 12).

Internal Factors

Four internal factors were identified as affecting amplitude shifts of the baseline curves. They are technical manufacturing risk, co-production, subsystem integration and program director's philosophy. Since all programs exhibit some degree of risk, the technical manufacturing risk factor was found to be a factor in all programs. The other three factors are program specific and may or may not be significant in developing manpower requirements.

Technical Manufacturing Risk (TMR)

This risk is the cumulative risk associated with the technological requirements to fabricate and assemble the system and subsystems. It also includes problems associated with the availability of critical materials required to manufacture the system or subsystem.

Technical risk is highest for any program at the program's inception and then declines as the program progresses. If there are any major changes in the design of the aircraft, the risk may temporarily increase but will tend to resume the downward trend. However, this risk seldom, if ever, equates to zero because of the potential effects of ECPs and changes in the availability of critical materials caused by man or nature. For this study, it is assumed that the risk represented by a PTMRF (discussed later) reaches a minimum value of 10.

An analysis of the TMR variable indicates that its resolution does not follow any specific curve but does follow basic patterns depending upon its value at DSARC I. Since TMR is a key consideration for a program to move from FSD into production, it appears that there is a minimum TMR level which must be attained for a program to receive production approval at DSARC III. An absolute minimum TMRF for DSARC III approval has not been ascertained, but it appears reasonable to assume that this level should not significantly exceed the average TMR expected for any set of subsystems. Consequently, a program that is comprised of subsystems whose manufacture is within the manufacturing state-of-the-art will experience little risk resolution as the program proceeds through the validation and FSD phases. The primary reason for this trend is that major manufacturing problems typically encountered with these systems occur with increased rates of production. Further analysis, however, indicates that a program with a relatively high TMR during the conceptual and validation phases will experience a high rate of risk resolution prior to DSARC III. The higher risk results from the requirement to reach the previously described minimum TMR level for DSARC III production approval.

Figure 8 depicts the risk resolution for programs with different levels of manufacturing risk. The development of the critical value is discussed in the following

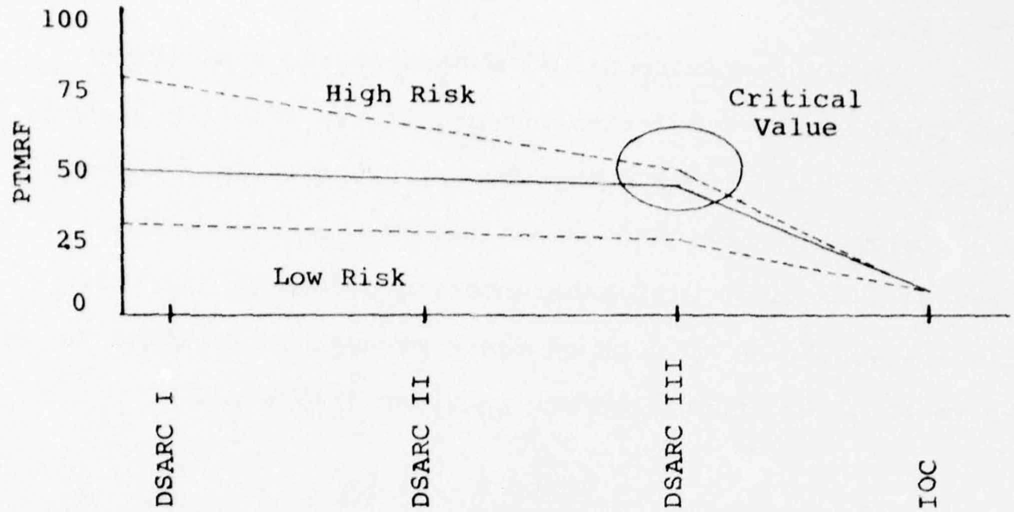

Fig. 8. Technical Manufacturing Risk

paragraphs. Of course, the production decision will also be, in part, dependent upon whether any subsystem remains a high risk item. But for long-range planning, the aggregate PTMRF appears to be an adequate comparative indicator of relative manufacturing risks among programs.

It is the magnitude of TMR that is the primary driver in determining the manufacturing engineering effort within the program office. This variable also significantly contributes to the manufacturing management and special review efforts. Unlike the previous factors, which are directly affected by technical risk, GFE is inversely a function of TMR. That is, the higher the TMR associated with any program, the lower should be the government furnished equipment management effort.

Total program technical manufacturing risk (PTMR) is defined as the cumulative effects of the relative state-of-the-art of all major subsystems; i.e., airframe, engines, avionics/electronics, and weapon delivery system (WDS). Based on interviews with manufacturing personnel (12; 13; 22), the weighting of each of these subsystems relative to the total manufacturing effort is shown in Table 2.

TABLE 2

WEIGHTING FACTORS

Subsystem	Weight
Airframe (A/F)	4.0
Engines (ENG)	2.5
Avionics/Electronics (A-V/ELECT)	2.5
Weapons Delivery System (WDS)	1.0

To determine a program's technical manufacturing risk factor (PTMRF), the weighting of each subsystem must be multiplied by a factor which illustrates or demonstrates the technological complexity for manufacturing the subsystem. Figure 9 defines key considerations to be used in determining the multiplier factor. For example, an airframe involving manufacturing technology which has never before been tried would warrant a complexity factor of 10.

Within state-of-the-art | Limited to new technology

1	5	10
Off-the-shelf	Major Design within S-O-A	New untried technology

Fig. 9. Technological Complexity

1--Previously manufactured, well within the state-of-the-art, essentially an off-the-shelf item. Management involvement is primarily monitorship or quality control.

5--Feasible under current technology but of a new design never before done on a large scale project.

10--High risk area involving manufacturing technology which has never been attempted before. May involve new materials, processes, or techniques.

NOTE: A minimum value of one was chosen rather than zero since there is always some element of risk in manufacturing a part or subsystem.

This factor when multiplied with the relative weight for the airframe, found in Table 2, would give a subsystem TMR factor of 40 (10x4=40). The program TMR factor for a composite system is simply the composite or summation of the applicable subsystems TMR factors.

For example, a program is entering the validation phase and consists of development efforts in all four subsystems. The airframe and engine are feasible with current technology, but the design is new, and there has never been a large scale production of either subsystem. The avionics and electronics are high risk areas involving new technology.

The WDS is well within the state-of-the-art. The PTMRF would be developed as follows:

Subsystem	Weighting	Complexity Factor	TMR Factor
A/F	4	5	20.0
ENG	2.5	5	12.5
A-V/ELECT	2.5	8	20.0
WDS	1.0	1	1.0
		PTMRF =	53.5

The PTMRF factor derived for this example is an indicator of the technical manufacturing risk associated with the program. This factor can be compared to other program TMR factors to determine relative manufacturing risk among programs.

Co-production

No mathematical formula has been developed for computing precise increases in manpower requirements due to co-production. However, it appears that co-production increases the manpower required to accomplish the manufacturing management and special review functions. The magnitude of these increases depends upon the categories of subsystems co-produced (i.e., airframe, engine, and electronics), the number of co-producing countries, the TMR of the subsystems, and the contractual arrangements employed.

As these sub-variables increase, the workload to accomplish the manufacturing management and special review functions also increases. This increase is due to increased planning, scheduling, and coordination resulting from the additional contractors.

It appears that several approaches have merit for determining manpower requirements due to co-production. The first technique is directly associated with the types of subsystems co-produced and the TMR involved. The second is associated with the number, geographical locations, and the manufacturing philosophies and capabilities of the co-producing countries. A third technique may be a combination of the first two techniques.

Based upon the experiences of the F-16 program office, it appears that at least one person is required as the program office interface and coordinator for the co-production effort. Also, the first technique, mentioned above, appears to be the most appropriate for determining additional manpower requirements, generated by co-production, to accomplish increased manufacturing management and special review functions. This latter observation may be due to the reasonably close proximity of the co-producing countries and somewhat similar manufacturing philosophies. These European countries were also essentially competent in the basic manufacturing requirements of the F-16.

System Integration

Contractually specified integrative roles of the program office are seen by some interviewed personnel as having a significant impact on the manufacturing management function (13). Others, however, feel that the program office is highly involved with the integrative role as a matter of course whether or not there are contractual requirements (12; 22). With the exception of the B-1 program, there have not been any recent major aircraft programs where an ASD program office assumed the subsystem integration role. Thus, although it is a potential variable, there were insufficient data available to reach any quantitative conclusions. However, it appears likely that contractually specified integration requirements do increase the manufacturing management effort. The magnitude of these effects is at best uncertain.

Program Director Philosophy

This internal variable has a direct bearing on the manning (allocations) of any functional organization within the program office. However, the program director's philosophy has little effect in determining actual manufacturing manpower requirements. This distinction is made because requirements are generated due to the basic functions, and internal and external factors previously identified in the overview. Therefore, the influence of the program director

more accurately affects the actual program manning than it does functional requirements.

However, the magnitude of the GFE management effort is one area that can be directly affected by the program director's philosophy. For example, the philosophy (or strategy) of relying upon contractor furnished equipment (CFE) rather than GFE can reduce the manpower required to accomplish the GFE management function. Conversely, a strong advocate of GFE can increase the manpower required to accomplish this function. In any event, the GFE management function is a requirement of the program office regardless of program director's philosophy. The program director's philosophy only tends to shift the amplitude of the manning required.

External Factors

External factors to the program also influence manufacturing manning requirements in the program office. As previously mentioned, these variables include such factors as: urgency of need, CAS manning/support, contractor capability, and FMS.

Urgency of Need (UON)

This variable implies that there are possible external pressures, such as national defense priorities and political visibility, which tend to affect the relative allocation of personnel to a program. However, these

factors can also have a direct bearing on the manpower requirements and assignment phasing of personnel.

Intuitively, a program would have an increase or decrease in its manufacturing manpower requirements if time periods between critical program milestones are shortened or lengthened. This phenomenon is simply a matter of reducing or increasing the time required to accomplish the same amount of work associated with the basic functions.

Consequently, UON does not affect the manufacturing functional requirements of a program (unless specific regulatory requirements are waived), but it does play a significant part in establishing the assignment phasing and manpower levels to accomplish the basic manufacturing functions.

An analysis of the impact of the UON variable indicates that it is (1) more pronounced during the validation and FSD phases, (2) influences all the manufacturing functions, and (3) can be considered a multiplier to the baseline curve. The research into this variable also suggests that a quantifiable value for UON can be computed as the ratio of baseline FSD divided by a program FSD. For example, the time between DSARC II and DSARC IIIA for the A-10 was eighteen months. The baseline for this same period was 25 months. Thus, a UON of 1.4 (25/18 = 1.4) was computed for the A-10 program.

Contractor Capability

This variable is a composite of factors, such as applicable contractor technological experience, which directly affects technical manufacturing risk; contractor facilities and equipment, in terms of adequacy and proposed additions; and manpower requirements, in terms of skill availability and proposed build-up rates. The weighting of this variable is totally subjective and is a function of technical program requirements versus existing and potential technical contractor capability.

As a general observation, a contractor possessing: (1) appropriate technological experience, (2) appropriate quantity and quality of facilities, machines, and equipment, and (3) the appropriate skill mix and number of personnel, will present fewer management problems to the program office than a contractor who is deficient in any one of these areas. Also, contractors who are not deficient in these areas will reduce the special review efforts since fewer deficient areas will be found, and the relative magnitude of follow-up reviews will be lessened.

Contract Administration Services (CAS) Manning/Support

Many of the program manufacturing functions are shared by program office personnel and CAS personnel, or, in some cases, program manufacturing functions may be

solely the responsibility of the CAS. Regardless of who has responsibility for a given function, these functions need to be accomplished to ensure the cost, schedule, and technical success of a program.

Therefore, the CAS manning and support capabilities become important in determining manpower requirements in the program office. In cases where CAS support is not available, the program office has the alternatives of: (1) increasing internal manning to accomplish neglected functions, or (2) requesting additional manpower allocations for the CAS through the CAS headquarters.

The critical period for full-time personnel support at the CAS begins in the later stages of the validation phase and continues through to the middle stages of FSD. This is due to the manpower build-up trend within the program office. The CAS support can provide on-site support and help familiarize program office personnel with current or potential problems with program and contractor progress. The familiarization can greatly expedite the learning process of new program office personnel while the actual CAS support can reduce program office workload.

Foreign Military Sales (FMS)

Normally, FMS begins during the production phase after initial production and USAF IOC. In this case, additional manpower is required to support the GFE function due

to duplicative efforts to acquire standard GFE items and the unique or peculiar aspects of the FMS aircraft. The duplicative effort is generated by regulatory requirements for separate funding and purchase requests, and the segregation of items procured for each country.

However, FMS may begin earlier in the program life cycle. In this case, there is a potential for increased difficulties and higher manning. These difficulties, for example, can result from accelerated aircraft deliveries which may cause deviations from approved production plans. The result of this situation would be increased efforts to accomplish the manufacturing management and GFE functions.

Baseline Manpower Curve

Before the baseline curve could be developed, a standard or normal program had to be defined. By definition, this program was assumed to involve all of the subsystems contained in Table 2 (i.e., airframe, engine, avionics/electronics, and weapon delivery systems), and all subsystems are assumed to involve normal development and manufacturing risk as defined in Figure 9. Furthermore, no co-production or FMS requirements were considered.

To develop the baseline curve, it was first necessary to determine a standard time between each phase point within the program acquisition cycle. The times used in this study are the mean phase times for the A-10, F-15, and

F-16. These mean times were used throughout the remainder of this study to provide a common basis for comparison. The amplitude of the baseline curve was obtained by summing the amplitudes of the four basic functions. The result of this effort was the standard baseline curve shown in Figure 10.

Since the program technical manufacturing risk appears to directly affect all of the basic functions, a PTMRF at DSARC I was computed for the standard program, described above, as shown in Table 3.

TABLE 3

STANDARD PROGRAM TECHNICAL MANUFACTURING RISK

Subsystem	Weighting	Complexity Factor	TMRF
A/F	4.0	5	20.0
ENG	2.5	5	12.5
A-V/ELECT	2.5	5	12.5
WDS	1.0	5	5.0
			PTMRF = 50.0

The following basic function curves are based on a PTMRF of 50, which represents the cumulative technical manufacturing risk of a standard program. As previously discussed under technical manufacturing risk, the standard

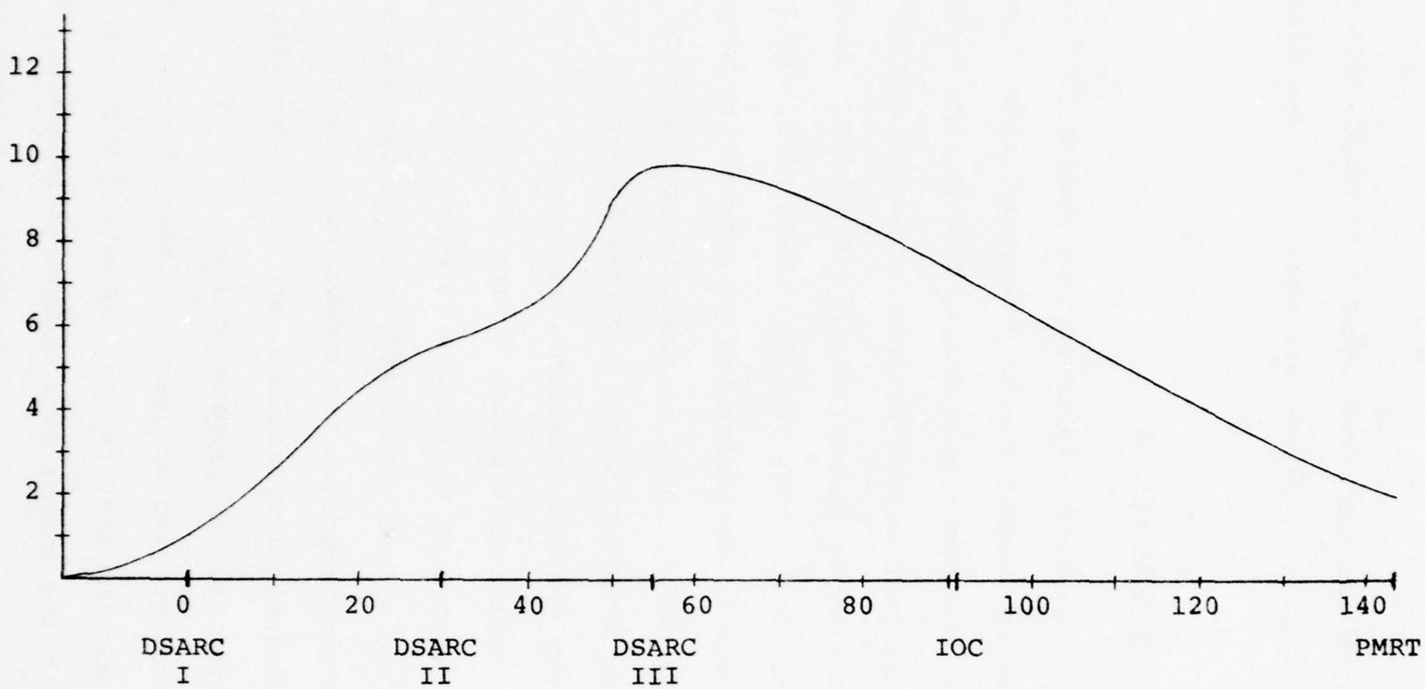

Fig. 10. Standard Baseline Curve

PTMRF remains constant from DSARC I to DSARC IIIA and then begins to decay at a fixed rate until IOC (see Figure 8, page 47).

Manufacturing Engineering (ME) Curve

As previously discussed, the manning for manufacturing engineering begins in the conceptual phase, peaks during validation, and diminishes during FSD and the production phase. Data from actual program documentation did not specify manning to accomplish this function. Consequently, regulations, i.e., DODI 5000.34, AFSCM 84-3, and ASDP 84-1, were reviewed to determine the phasing of the manufacturing engineering tasks. And, personal interviews were used to discuss the manpower levels required to support these tasks.

From these discussions, it appears that the manufacturing engineering effort during the conceptual phase and the early stages of validation is primarily a liaison and coordination effort. This effort is required to ensure that proposing contractor(s) are conducting production feasibility and producibility studies, and to ensure that Air Force laboratories and the program office are aware of the progress, findings, and adequacy of these studies. While the absolute manning required to accomplish this effort may depend upon the number of contractors involved, it appears that at least one person is required to perform the

manufacturing engineering during the conceptual phase for a program with a TMRF = 50.

As the program proceeds through validation, producibility studies should become more refined. This refinement permits the manufacturing engineer to analyze the studies and prepare detailed plans for the implementation of producibility recommendation. Consequently, the effort to accomplish the manufacturing engineering function increases during validation.

This increased manning requirement continues into FSD as producibility recommendations are implemented, technical manufacturing problems are encountered, and ECPs occur. As a result of the increased activity to monitor the implementation of the producibility recommendations, resolve the manufacturing problems, and evaluate the ECPs, manpower to accomplish the manufacturing engineering function for a program with a PTMRF = 50 approximates two man-years during peak FSD requirements.

After initial production articles have been accepted, the manufacturing engineering effort is primarily concerned with the evaluation of ECPs and modifications. Consequently, the manning to accomplish the manufacturing engineering functions declines during the production phase to approximately one person at IOC for the "standard program." Figure 11 shows the manufacturing engineering manpower curve for the standard program.

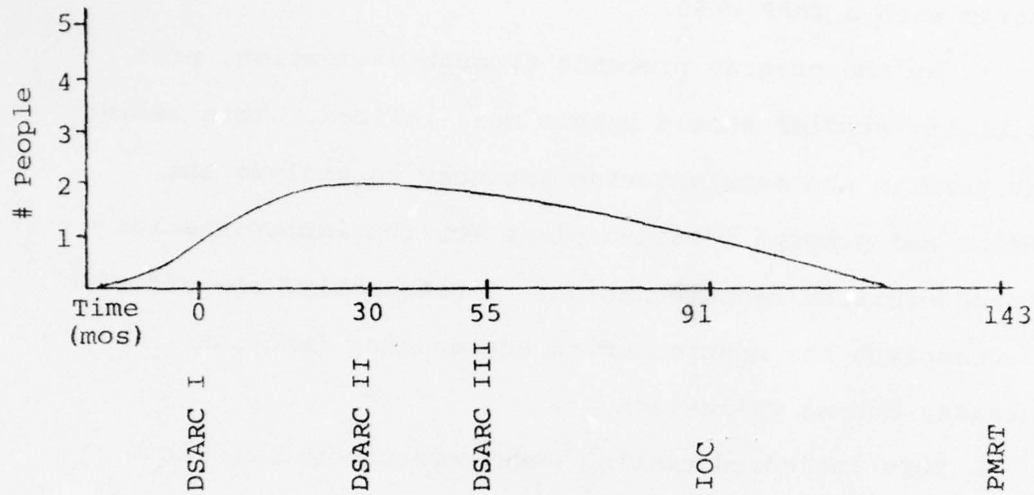

Fig. 11. Manufacturing Engineering Requirements

Manufacturing Management (MM) Curve

Manufacturing management manpower requirements appear to be a function of technical manufacturing risk, co-production, FMS, subsystem integration, contractor capability, and CAS support. However, only the technical manufacturing risk variable was consistently evidenced in all programs and warranted consideration in developing the basic function curve for manufacturing management. However, the other variables, when evidenced, except CAS support and contractor capability, appear to have an additive effect upon manpower requirements to accomplish this function. There appears to be an inverse relationship between contractor capability and program manning requirements.

An inverse relationship also appears to exist between program manning requirements and CAS support.

The manufacturing management trend curve shown in Figure 5 indicates that initial manning to accomplish this function begins in the later stages of validation. Subsequent manning requirements rapidly accelerate to peak requirements during early FSD and begin to diminish after acceptance of initial production articles.

Intuitively, the manning required to accomplish this function fluctuates as the level of technical manufacturing risk fluctuates. This results from increased efforts in planning, scheduling, monitoring, coordinating, and problem-solving activities associated with increases in technical manufacturing risks of a program. That is, a program with higher TMRF requires greater management effort than a program with a lower TMRF.

Thus, it follows that the manpower required to accomplish the manufacturing management function can be determined by: (1) computing the PTMRF, and (2) determining the technical manufacturing risk level that can reasonably be expected to be managed by one person. Once both factors are known, the ratio of PTMRF to the technical manufacturing risk that can be managed by one person determines the number of persons who should be assigned to satisfy this function.

After reviewing program manufacturing organizations and discussing the manufacturing management workload generated by TMR, it was determined that:

1. An engine experiencing normal development and manufacturing risk can be expected to require at least one person to accomplish the manufacturing management function.

2. The same effort, i.e., at least one person, can be expected to accomplish this function for the avionics/electronics with normal manufacturing risk.

3. The effort to accomplish this function for the airframe was considered to be greater than one man-year, and the effort to manage the WDS was considered to be less than one man-year (10; 12; 13; 22).

Recognizing that the engine and the avionics/electronic subsystems for a standard program are each considered to generate manpower requirements of at least one person, the TMRF computed for each of these subsystems (Table 3) are considered to be the standard TMR level that can be expected to be managed by one person. That is, it appears that at least one full-time manufacturing person would be required for every 12.5 (2.5 weight x 5 complexity factor) increment in the PTMRF computed for a program prior to DSARC IIIA. After DSARC IIIA, a ratio between program TMR and the standard program TMR would need to be computed and multiplied against the projected manpower requirements

shown in Figure 12. The resulting value should indicate the program's manpower requirement to accomplish this function.

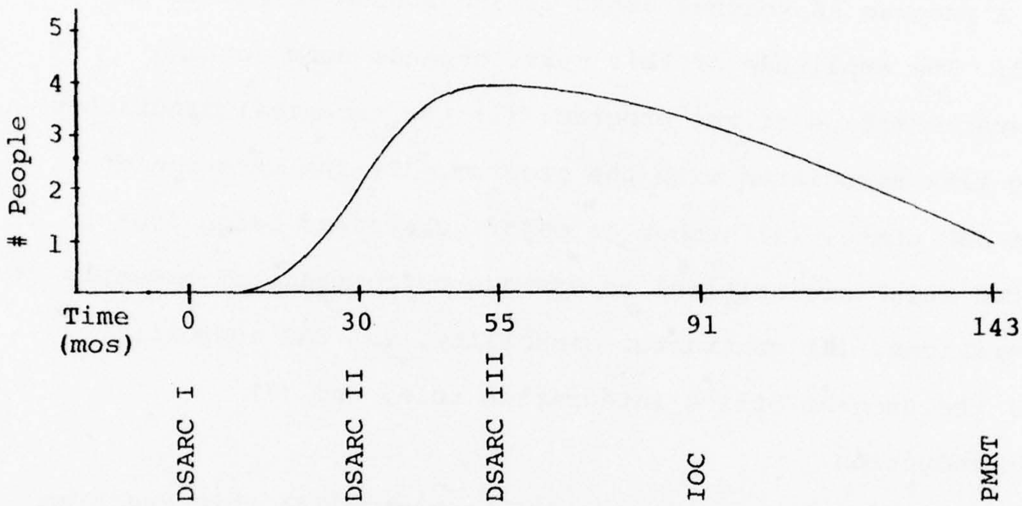

Fig. 12. Manufacturing Management Requirements

Since the PTMRF for a standard program at DSARC I equals fifty (50), the peak manpower requirement to accomplish the manufacturing management function for the standard program is four (4) people. This peak requirement and assignment phasing is shown in Figure 12. Since the standard baseline curve does not include the effects of co-production or the integrative role, the curve will shift upwards if these variables are present. The magnitude of this shift is discussed under each of the specific variables.

Special Review (SR) Curve

As can be seen in Figure 6, manning for special reviews should begin during the later stages of validation as a program approaches DSARC II and source selection for FSD. The amplitude of this curve depends upon certain characteristics of the program: (1) the technical manufacturing risk associated with the program, (2) the duration of the FSD phase, (3) number of major subsystems being produced which are critical to systems performance or assembly operations, (4) contractor capability, (5) CAS support, (6) the program office integration role, and (7) co-production.

Initial manning required to accomplish this function is generated by Manufacturing Management/Production Capability Reviews (MM/PCR). These reviews are required to be conducted concurrently with source selection activities for the FSD contractor. It is the opinion of personnel interviewed that leaders or, at least, key participants in these reviews should be members of the program office manufacturing team. Consequently, these personnel should be identified during the later stages of validation, and be assigned to the program for, at least, the duration of FSD.

This last assertion does not mean that there should be at least one person assigned to accomplish special reviews for each contractor being reviewed during the source selection. All special manufacturing reviews are considered

to be an extension of the manufacturing management function, but they warrant sufficient manning to be considered separately in determining total manufacturing manpower requirements. In other words, manning requirements to accomplish special reviews should be considered as augmentation to accomplish overloads associated with the manufacturing management function.

This means that actual manning to accomplish special reviews should consider: (1) MM/PCR surge requirements, (2) manning requirements to accomplish Production Readiness Review (PRRs), and (3) special impact studies generated by proposed contractual changes. Ideally, this would mean workload leveling through advanced planning to accomplish these reviews within the time constraints of the contractually specified FSD phase.

Given that proper planning for special reviews will be accomplished during validation by these persons responsible for the manufacturing management function, the specific manpower augmentation required to accomplish the special reviews can be computed by analyzing (1) the number and categories of subsystems for which special reviews are planned, (2) the duration of the planned reviews, and (3) the preparation and completion time of the reviews. This analysis permits the computation of total man-hours per subsystem category which can be used to determine manpower and phasing requirements. Recognizing that there is

an overlap between the manufacturing management and special review functions and that special reviews are an extension of the manufacturing management function, it is intuitive that full-time manning to accomplish special reviews should be less than that required for the manufacturing management function.

The manning level to accomplish the special review function shown in Figure 13 was computed by assuming that: (1) a standard program would require quarterly manufacturing reviews of two-week duration for each of the airframe, engine and avionics/electronics subsystems and one week per quarter for the weapon delivery system; (2) follow-up reviews would be conducted bi-monthly with an average of one week duration for each major subsystem; and (3) time for planning, coordinating, report writing, and travel is equal to the time required to conduct each review. Computations based upon these assumptions are shown in Table 4. The results are twenty-two man-weeks per quarter or eighty-eight man-weeks per year which equates to two (2) man-years required for the standard program. The two man-year requirement is not intended to be a firm non-refutable requirement, but, rather, a baseline for planning purposes when firm program special review plans are not available.

TABLE 4

QUARTERLY REQUIREMENTS (MAN-WEEKS)

	BASIC			FOLLOW-UP			
Subsystem	Prep	Perform	Plan Report	Prep	Perform	Plan Report	Total
Airframe	1	2	1	½	1	½	6
Engine	1	2	1	½	1	½	6
A-V/ELECT	1	2	1	½	1	½	6
WDS	½	1	½	½	1	½	4
							22

NOTE: 4 quarters x 22 man-weeks = 88 man-weeks/annum.

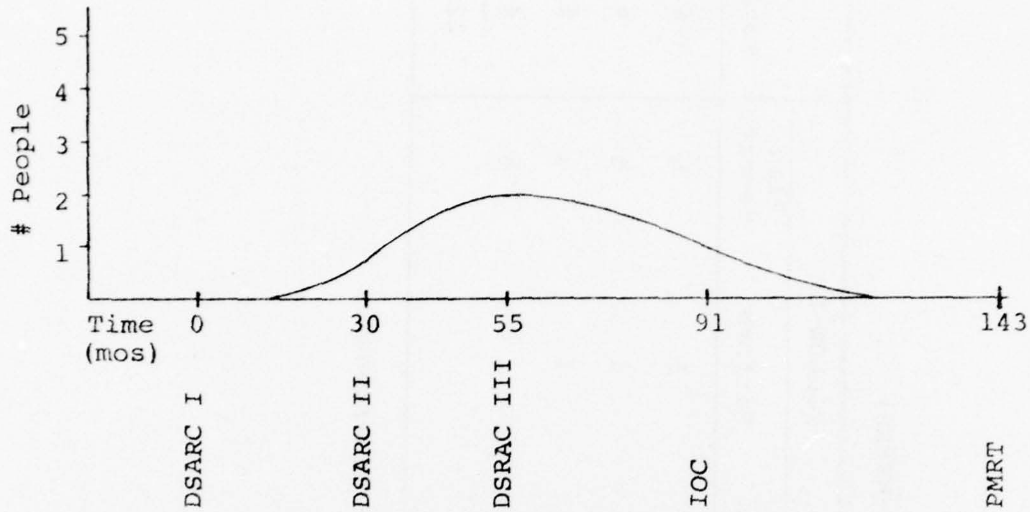

Fig. 13. Special Review Requirements

When available, program plans and scheduled milestones should be the basis for determining actual requirements. Requirements to support a program can be determined using these schedules and milestones and the computation techniques shown in Table 3.

Government Furnished Equipment (GFE) Management Curve

Design stability, the number of FMS cases associated with a program, and co-production appear to have a direct impact upon the magnitude of the GFE management effort. Program director philosophy regarding GFE versus CFE also has an impact upon the magnitude of this effort.

It also appears that the magnitude of the GFE management effort is reasonably constant among existing

programs when the effects of FMS and co-production are not considered (11; 12). For example, the increased manning to accomplish the GFE function for the F-16 program relative to the F-15 program appears to be a result of early decisions, by the European Consortium during FSD, to make a firm commitment for production of the F-16.

This commitment, in turn, required early GFE personnel involvement to identify, schedule, and monitor GFE items to support the European commitment. Regulations which require separate funding, purchase requests, schedules, and monitoring activities for each country procuring the F-16 also added to the level of effort in the F-16 program. Additionally, the F-16 co-production effort generated requirements for the program GFE management personnel to develop plans and schedules to support two assembly lines in Europe and one assembly line in the United States. When considering the GFE manning for the F-16 program without FMS and co-production requirements, both the ASD manufacturing staff and F-16 GFE personnel agree that the present effort would be significantly reduced (11; 13).

Through further discussions with these personnel, it was agreed that peak manpower requirements to support the GFE management function in a standard program would approximate two persons. This number assumes: (1) manning during the validation phase for planning and Request for Proposal preparation; and (2) staff support for analyzing

GFE requirements during FSD and production phase source selections.

Consequently, a standard program's projected baseline requirements to accomplish the GFE management function, shown in Figure 14, reflects one person during the validation phase (external support required during source selections) and two full-time persons from late FSD through IOC. Peculiar requirements for FMS and co-production would significantly increase this number and possibly shift the time phasing of the manning requirements. After IOC, the requirement for two full-time persons for GFE would normally decrease to zero after PMRT if there were no major modifications or changes to the program. Program director philosophy of maximum reliance upon contractor furnished equipment would reduce the overall requirement but not appreciably.

Application of Baseline Curve

The standard baseline manpower curve shown in Figure 10 was developed to predict the average magnitude and standard phasing of manpower required to accomplish the manufacturing functions for major ASD fighter programs. It appears, however, that this baseline curve, and the analysis process used to develop it, can be used to predict manufacturing manpower requirements for any major ASD fighter program.

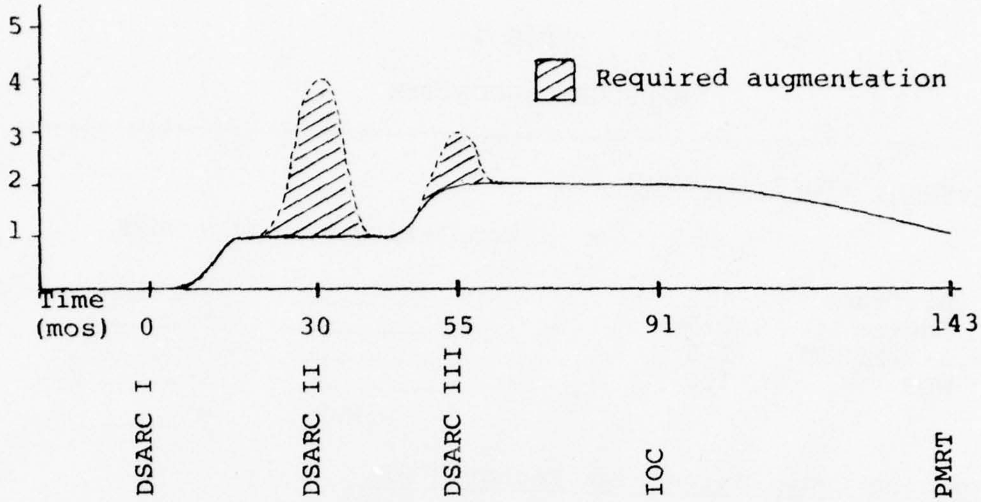

Fig. 14. Government Furnished Equipment Requirements

Table 5 contains the algorithm developed to determine manpower requirements based upon specific program variables. The first step is to determine the comparative risk of the program under consideration. This risk can be obtained by dividing the program's TMR factor by the standard value of PTMRF (Comparative Risk = PTMRF/Std). A value greater than one indicates that a program is more complex in manufacturing requirements than the standard program. For a value less than one, the converse is true. The comparative risk factor is then used to determine the shift in amplitude of the manufacturing management and manufacturing engineering functions.

Combining the magnitudes of the basic functional manpower requirements and including supervisory personnel,

TABLE 5

MANPOWER ALGORITHM

Determine PTMRF (Σ TMRF):

	Wt	x	Complexity Factor	=	TMRF
Airframe	4			=	____
Engine	2.5		________	=	____
A-V/ELECT	2.5		________	=	____
WDS	1.0		________	=	____
			PTMRF	=	____

Determine Comparative Risk Factor (CRF):

CRF = PTMRF/PTMRF of std program
CRF = _____/50 . . . up to DSARC IIIA

Determine interim manpower requirements:

Function	Baseline	x	CRF	=	Total
Director	1		N/A	=	1
Manufacturing Mgt	4		___	=	_____
Manufacturing Engr	1.8		___	=	_____
Special Reviews	2		N/A	=	2
GFE Mgt	2		N/A	=	2
			Total	=	_____

Determine final manpower requirements:

Obtain program time from DSARC II to DSARC IIIA, ___mos.
Baseline time = 25 months
Urgency of need (UON) = baseline time/program time
UON = 25/_______

Projected peak manpower at(DSARC IIIA) =
(interim peak manpower) x (UON)

Manpower requirements at any point in time equal projected program manpower at DSARC IIIA divided by the baseline value of DSARC IIIA multiplied by the baseline value at the time of interest.

$$\text{Manpower} = \frac{\text{Program Peak}}{\text{Baseline Peak}} \times \text{(Baseline value at time of interest)}$$

an interim value of manpower requirements can be obtained. This value must then be multiplied by the UON factor to develop a peak program requirement prediction.

This peak manpower prediction should occur at DSARC IIIA as does the standard program requirements. Thus, the predicted value can be compared to the standard program peak requirements to determine a ratio of predicted requirements to standard requirements. In turn, this ratio can be used to complete the predicted manpower requirement curve for the life of the program under consideration. This is done by simply multiplying standard manpower requirements by this ratio at critical milestones and plotting the points.

Recognizing that this process only provides a baseline predicated upon PTMR and UON factors, the resulting curve should be adjusted to reflect the effects of other variables, such as co-production, FMS, CAS support, and so forth, upon manpower requirements. As any program evolves through the acquisition life cycle, other information becomes known, and the external variables may change. Consequently, the predicted manpower curves are not static and should be reassessed as new information becomes available and the effects of the variables change.

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Summary

This chapter has provided a detailed analysis of the four basic functions, the internal and external variables, and the interaction of the functions and variables. Once these interactions were documented, a standard program was defined, and this information was used to develop the standard baseline curve previously shown in Figure 10. The chapter concluded with the development of an algorithm which can be used for predicting a program's manufacturing requirements by modifying the standard baseline curve according to the effects of the applicable variables upon the program.

In Chapter IV, the standard baseline curve is used to predict average manpower requirements for ASD fighter programs.

CHAPTER IV

COMPARATIVE ANALYSIS

Overview

This chapter contains the comparative analyses of manpower predictions using the standard baseline curve and the manpower algorithm developed in Chapter III. The first section compares the actual average manpower authorizations of the A-10, F-15, and F-16 programs to the predicted manpower requirements for the standard program. The last section compares specific program projections to the actual authorizations experienced by each program.

Baseline Comparison

Manpower data for the A-10, F-15, and F-16 programs were collected, and curves were developed for each program to show actual program manpower authorizations as each program evolved through the acquisition process. In all cases the actual curves were not complete, since the data were either unavailable, classified, or yet to be generated. No evidence was found that any manufacturing manpower authorizations existed prior to DSARC I for any of the programs. Specific manpower authorization curves are discussed in the comparative analysis section for each program.

The duration of each phase for the three programs studied differed significantly. This difference complicated the comparison of manning authorizations and, thus, it was necessary to develop a mean time for each phase. Figure 15 shows the resulting manpower authorizations of each program in relation to the normalized (mean) phase durations.

As shown in Figure 15, manufacturing manpower authorizations increase from relatively low levels at DSARC II to peak requirements approximately one year after DSARC IIIA. Additionally, it is evident that the manpower authorization levels differ significantly among the programs.

A basic assumption for this study was that a standard baseline curve would approximate the average manpower requirements of ASD fighter programs. Therefore, an average curve based upon the data collected for the three programs was developed. Figure 16 reflects the mean manpower authorizations and the previously determined standard baseline curve using the mean phase duration for the abscissa. As can be seen by comparing the two curves, predicted requirements initially overestimate actual authorizations until the middle of the FSD phase and then underestimated actual authorizations for the remainder of the acquisition cycle. The comparison also shows an approximate one-year

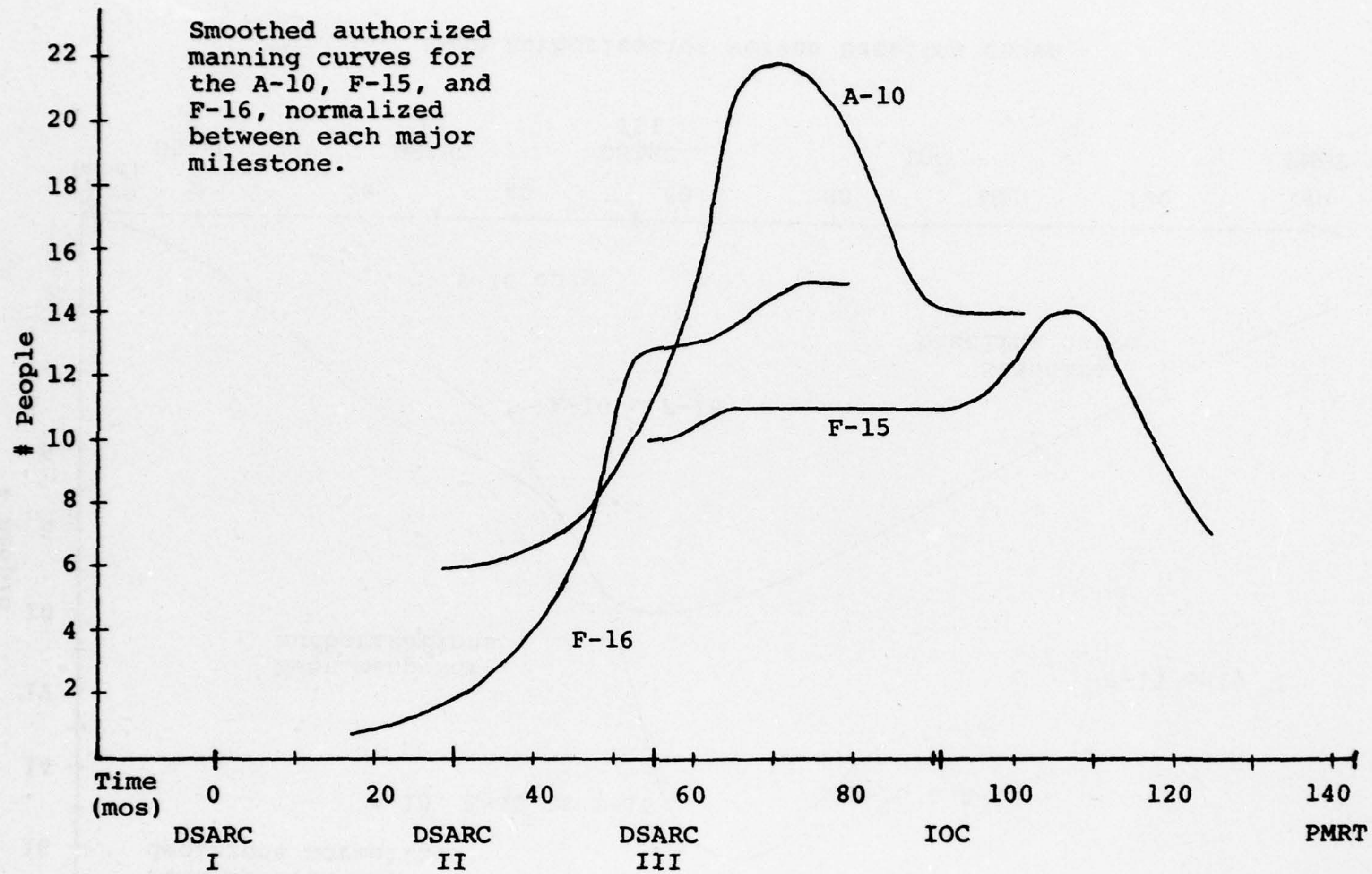


Fig. 15. Actual Authorization Curve

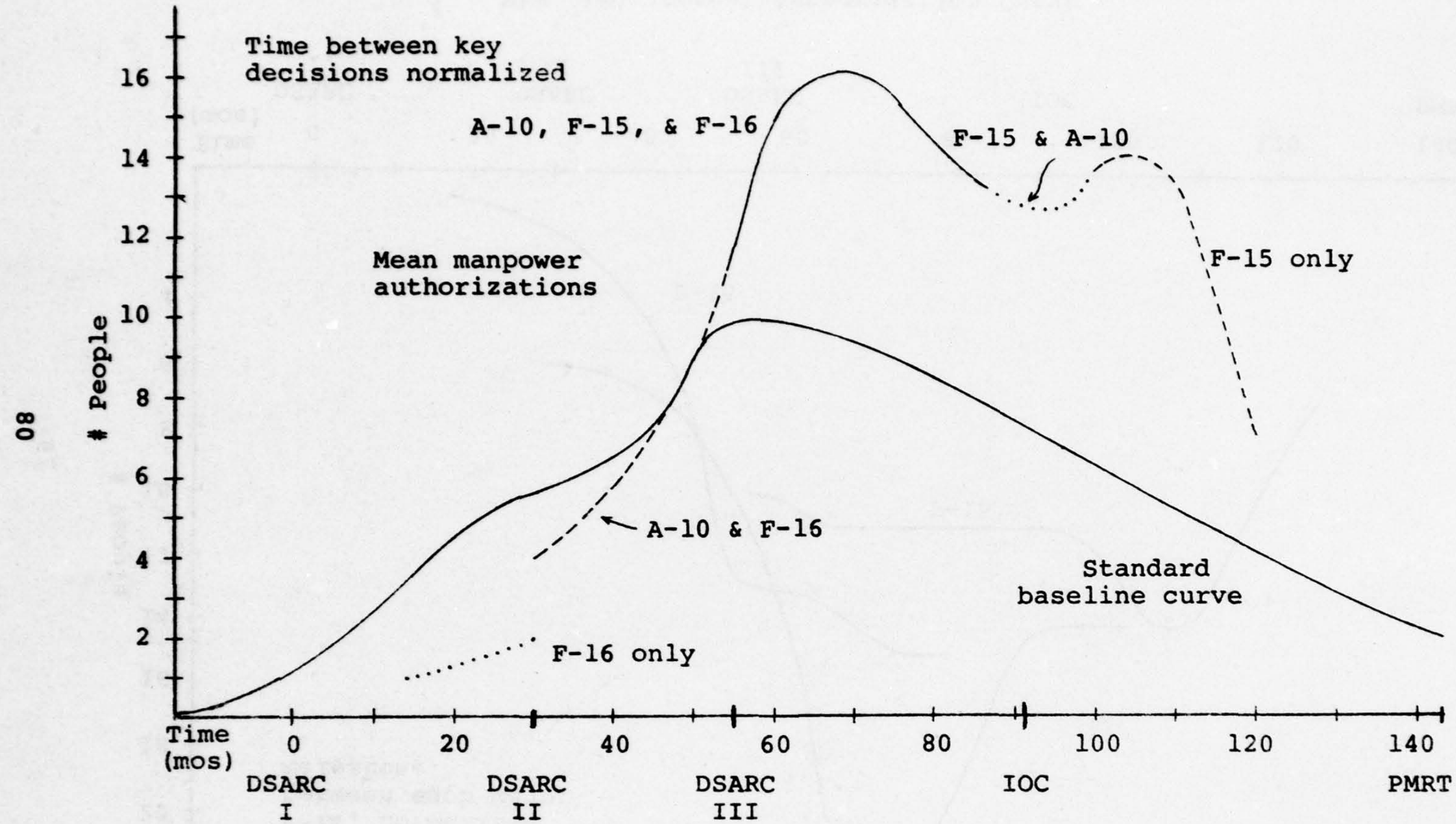


Fig. 16. Mean Authorization versus Baseline Curve

delay from peak projected requirements to peak authorizations.

The apparent overestimate of requirements is primarily due to changes in Air Force policy and regulatory guidance which specify early manufacturing personnel involvement. Some of these changes (i.e., specified requirements for producibility reviews) have occurred since the programs were in their validation phase. Also, the standard baseline curve represents what the researchers have determined to be ideal manpower phasing to accomplish the required manufacturing functions. This phasing is explained in Chapter III for each basic function.

The apparent underestimate of requirements after IOC appears to be a result of workloads created by modifications and retrofit activities. These two activities were not considered as variables when developing the model. However, subsequent discussions with program office personnel, after the data analyses, indicate that these activities do have a significant impact upon the manufacturing and GFE management functions.

The lower peak requirements shown by the standard baseline curve in Figure 16 was expected since the baseline does not include the effects of such variables as co-production and FMS. In addition, the standard baseline curve does not include the requirement for supervisory

personnel such as the program manufacturing director or deputy directors.

If personnel authorizations directly attributable to above variables were subtracted from the mean actual authorizations curve, the peak authorization would be reduced to approximately thirteen (13) authorizations. However, the standard baseline curve would still underestimate the peak mean authorizations of the three programs.

Another possible explanation for these underestimates is also applicable to the lag between peak requirements and authorizations. The mean actual curve represents authorizations. The baseline curve represents requirements. A third curve, not shown because of insufficient data, would have been the actual assignment of personnel.

Ideally, there should be no discrepancy between requirements, authorizations, and manning. However, the analysis of the ASD manpower process indicates that authorizations are predicted based upon existing workloads. Once authorizations are approved, efforts to fill the authorizations are initiated. Since normal personnel acquisitions cannot be accomplished on short notice, an inherent lag between approving and filling an authorization exists.

This situation has the potential for increasing manpower requirements by creating work backlogs which must be accomplished prior to critical program milestones such as DSARC III. The criticality of this lag is a function of

the time between manpower requirements and actual manning, and the rate of change in workload.

When actual manning lags authorizations for an extensive time, it is also possible that certain tasks may be given minimal effort and considered completed in order to satisfy milestone requirements. If this occurs and decisions are made to proceed, the tasks which generated the additional authorizations may no longer be required or the potential for future problems which generate additional workloads may be created. The first situation results in over manning when authorizations are eventually filled. The second situation leads to increased requirements and subsequent increases in authorizations.

Therefore, the difference between peak projected requirements and authorizations may be partly attributable to the inherent lag in the ASD manpower process. That is, the lag may contribute to late identification of problems and a cumulative build-up in work backlogs. This, in turn, delays normal task completion and generates peak manpower authorizations at a later point in the program life.

Although differences existed between the standard baseline curve and the actual mean manpower curve, these differences can be explained by the differences in information presented. The standard baseline curve was developed to reflect ideal manpower phasing to accomplish the manufacturing functional requirements based upon current

Air Force policy and regulatory guidance. The actual mean authorization curve reflects historical authorizations which were based upon existing workloads at a given point in time.

Program Office Authorization Analysis

The previous section of this chapter discussed a general comparison of the standard baseline curve to the average manpower authorizations experienced by the A-10, F-15, and F-16 program offices. The remainder of this chapter is devoted to developing a baseline curve for each of these programs, comparing the baseline predictions to actual authorizations, and explaining the deviations through the analysis of specific program variables. Data used in the analyses were collected through interviews with program office and the ASD staff manufacturing personnel (12; 13; 21; 26).

Senior co-located personnel, in each program office, developed a PTMRF for their respective program based upon the TMR perceived at DSARC I or a similar decision point, and the Chief of Manufacturing for the ASD staff developed an independent PTMRF for each program for the same decision point. The independently developed PTMR factors, shown in the analysis section for each program, were then analyzed and compared.

Only the F-16 PTMRF showed appreciable differences in the independen[illegible]ctor development. However, subsequent

discussion with the personnel who developed the F-16 PTMRF indicated that a closer agreement could have been reached if the factor or program peculiarities had been mutually discussed. Consequently, the average PTMRF for each program was used to develop respective program baseline curves.

A-10 Manpower Analysis

Table 6 shows the development of the PTMRF, the comparative risk factor for the A-10 program at DSARC I, and the development of peak projected manpower requirements based upon the comparative risk and urgency of need factors. Figure 17 compares the A-10 baseline curve, that could have been developed at DSARC I, to the actual authorizations experienced by the program.

This comparison shows that predicted requirements peaked earlier and at a lower level than actual authorizations. The lag in actual authorizations can be explained by the current methods of predicting requirements, authorizing positions, and filling the authorizations as previously discussed. The low level of predicted peak requirements is a result of many reasons.

Factors which would have caused higher predictions were not known at DSARC I and manufacturing problems encountered in the A-10 program were caused by external variables; i.e., contractor capability, CAS manning, and timely filling of manufacturing manpower authorizations.

TABLE 6

SUMMARY OF A-10 CALCULATIONS

PTMRF Development

Subsystem	Staff	Program Office
Airframe	16.0	14.0
Engine	7.5	11.3
A-V/Elect	7.5	2.5
WDS	5.0	7.5
	36.0	35.3

Average Program PTMRF = 35
Standard Program PTMRF = 50
Comparative Risk Factor (CRF) 35/50 = 0.7

Manpower Determination

Function	Baseline	x CRF	= Total
Director	1	-	1
Manufacturing Mgt	4	.7	3
Manufacturing Engr	1.8	.7	1
Special Reviews	2	-	2
GFE Mgt	2	-	2
			9

Program time (DSARC II to DSARC IIIA) = 18 mon
Baseline time (DSARC II to DSARC IIIA)= 25 mon
UON 25/18 = 1.4
Projected peak manpower 9 x 1.4 = 13

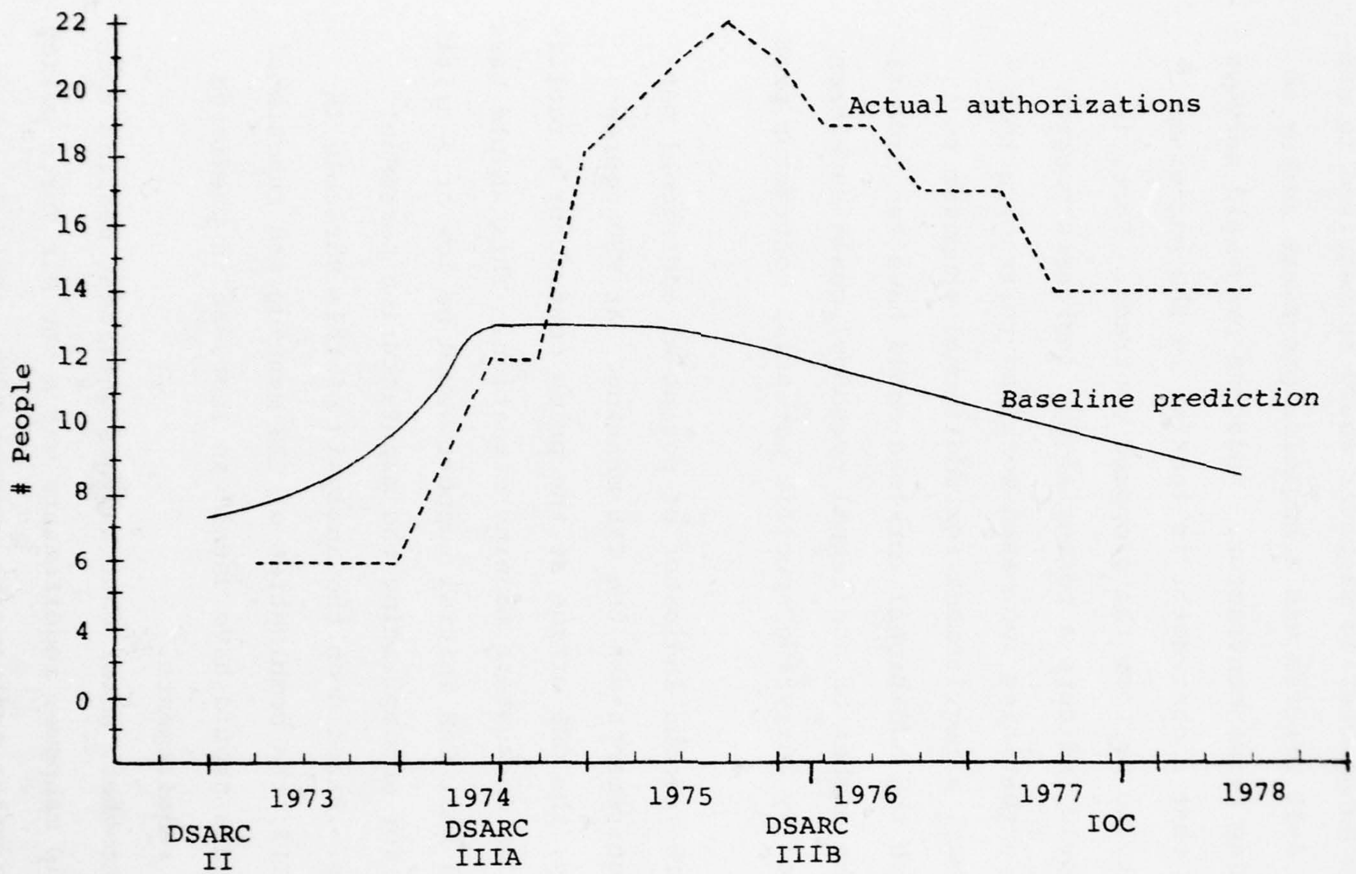


Fig. 17. A-10 Manpower Comparisons

An indication, at FSD source selection, that increased manufacturing manpower would be required to support the A-10 program was a negative pre-award survey on the winning prime contractor. Negative pre-award surveys indicate that a contractor is lacking in the perceived capability to perform the proposed contract. This, in turn, should indicate a potential for increased program risk and a resulting increased workload to resolve this risk. Thus, a requirement for additional manpower to accomplish the additional workload could have been identified. The number of additional personnel could have been determined by analyzing specific potential contractor problems.

The second indicator of potential additional manpower requirements was the CAS manning. At FSD source selection, the CAS office at the prime contractor's facilities was in an austere manning situation. This should have indicated that CAS initial support would be low at a critical time for accomplishing the manufacturing personnel functions. Based upon the analysis of this variable in Chapter III, the combination of CAS manning and functional requirements should have caused an increase in predicted manpower requirements.

Another factor that had a significant bearing upon early A-10 manpower requirements was a new Air Force policy directing major programs to conduct PRRs. This direction

created the special review function and additional workloads not previously mandated for major programs. Consequently, manning to approved authorization levels was a necessity to accomplish this additional workload.

At FSD source selection, the A-10 program was authorized six (6) manufacturing personnel, but only three (3) were assigned to the program at that time. As a result of additional workloads created by the contractor's capability, CAS manning, special reviews, and actual manning, normal manufacturing management activities suffered.

While these conditions existed, the scheduled completion for FSD and DSARC III remained firm. This further increased manpower requirements since the time remaining to resolve the increasing contractor's management and manufacturing problems was decreasing. The net result was an increased urgency of need for additional manufacturing personnel.

The continued low manpower predictions after IOC stem primarily from effects of modifications and retrofit efforts which were not considered in the baseline computations. From discussion with the A-10 director of manufacturing (26), it appears that the modifications and retrofits generated increased manpower requirements upon the manufacturing and GFE management functions. The increased effort is not a result of technical manufacturing risk, but, rather, a result of subsystem design stability.

F-15 Manpower Analysis

Table 7 shows the development of the PTMRF, the comparative risk factor for the F-15 program at DSARC I, and the development of peak projected manpower requirements based upon the comparative risk and urgency of need factors. Figure 18 compares the F-15 baseline curve, that could have been developed at DSARC I, to the actual authorizations experienced by the program.

This comparison reveals that the projected manpower requirements underestimate actual authorizations, and that peak authorizations occur after IOC which was much later than expected. The apparent inconsistency with authorizations peaking after IOC resulted from reductions in authorized positions at CAS locations, which were transferred to the F-15 manufacturing division. These authorizations were never filled and were subsequently cancelled. Removing these authorizations from the F-15 program, peak authorizations for the F-15 division would have peaked after DSARC IIIB and continued beyond IOC.

After this adjustment, the curves would show a much smaller discrepancy between predicted requirements and actual authorizations. The delay between predicted requirements and authorizations may also be explained by the ASD manpower process as previously discussed.

The increasing discrepancy between predicted and actual authorizations after DSARC IIIB can, in part, be

TABLE 7

SUMMARY OF F-15 CALCULATIONS

PTMRF Development

Subsystem	Staff	Program Office
Airframe	30.0	32.0
Engine	20.0	20.0
A-V/ELECT	20.0	12.5
WDS	6.0	10.0
	76.0	74.5

Average Program PTMRF = 75
Standard Program PTMRF= 50

Comparative Risk Factor (CRF) 75/50 = 1.5

Manpower Determination

Function	Baseline	x CRF	= Total
Director	1	-	1
Manufacturing Mgt	4	1.5	6
Manufacturing Engr	1.8	1.5	3
Special Reviews	2	-	2
GFE Mgt	2	-	2
			14

Program time (DSARC II to DSARC IIIA) = 34 mon
Baseline time (DSARC II to DSARC IIIA) = 25 mon
UON 25/34 = 0.7
Projected peak manpower 14 x 0.7 = 10

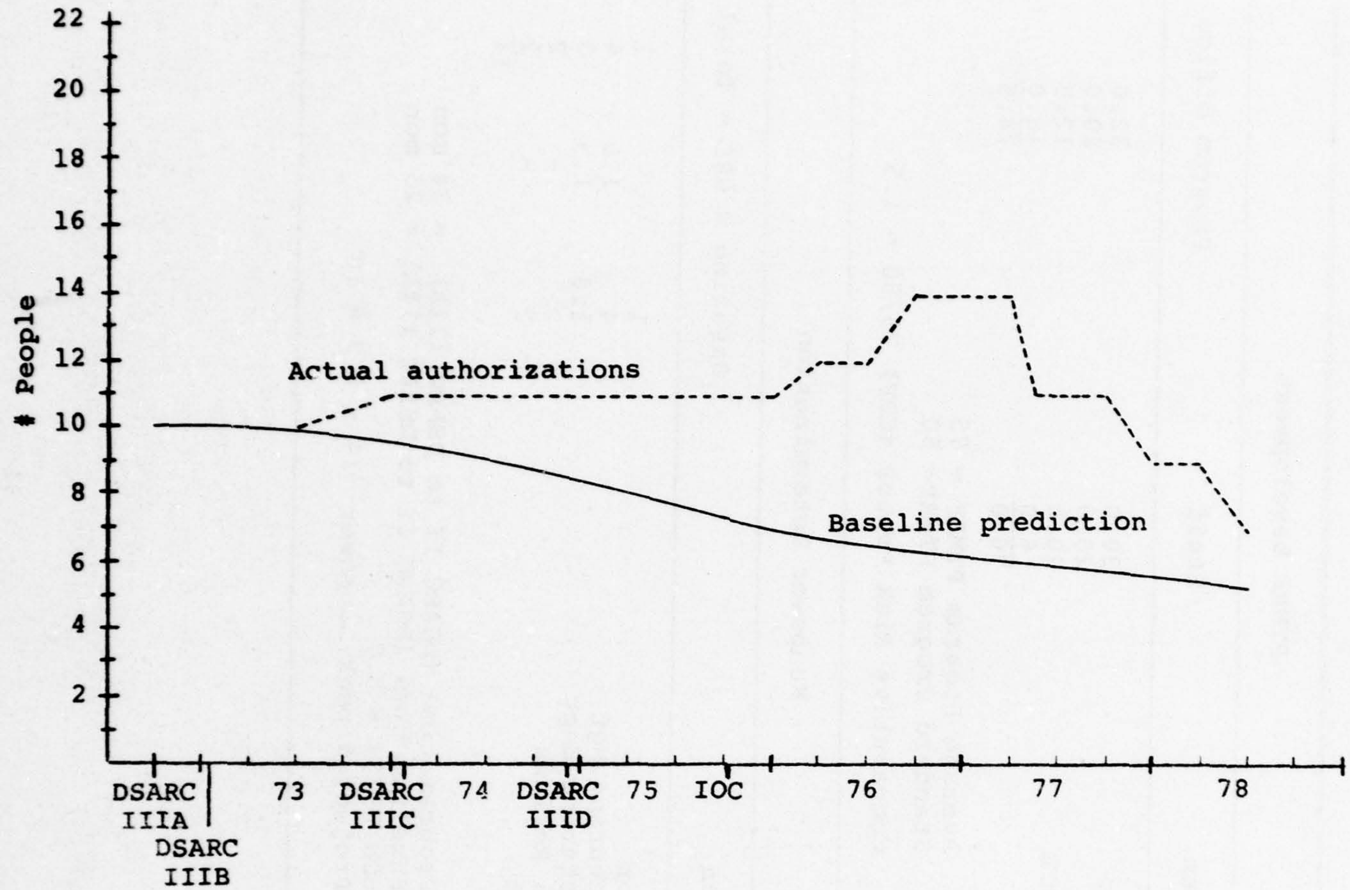


Fig. 18. F-15 Manpower Comparisons

explained by problems encountered with the F-15 Tactical Electronic Warfare System. The affects of modification and retrofits, as previously discussed, may also partially explain the low predictions after IOC. It is also important to note that the CAS manning to support the F-15 was available during the critical development periods. The F-15 prime contractor also had existing manufacturing facilities and management systems that were compatible with DOD requirements.

F-16 Manpower Analysis

Table 8 shows the development of the PTMRF, the comparative risk factor for the F-16 at DSARC I, and the development of peak projected manpower requirements based upon the comparative risk and urgency of need factors. Figure 19 compares the F-16 baseline curve, that could have been developed at DSARC I, to the actual authorizations experienced by the program.

This comparison reveals that early authorizations are substantially below predicted requirements and that authorizations do not meet predictions until late FSD. The figure also shows an abrupt increase in authorizations, prior to DSARC IIIA, at which time authorizations surpassed predictions and remained higher. Peak authorizations also occur later than peak requirements which is consistent with the average manpower trend.

TABLE 8

SUMMARY OF F-16 CALCULATIONS

PTMRF Development

Subsystem	Staff	Program Office
Airframe	20.0	26.0
Engine	7.5	13.8
A-V/ELECT	20.0	15.0
WDS	4.0	6.0
	51.5	60.8

Average Program PTMRF = 55
Standard Program PTMRF = 50
Comparative Risk Factor (CRF) 55/50 = 1.1

Manpower Determination

Function	Baseline	x CRF	= Total
Director	1	-	1
Manufacturing Mgt	4	1.1	4
Manufacturing Engr	1.8	1.1	2
Special Reviews	2	-	2
GFE Mgt	2	-	2
			11

Program time (DSARC II to DSARC IIIA) = 23 mon
Baseline time (DSARC II to DSARC IIIA) = 25 mon
UON 25/23 = 1.1
Projected peak manpower 11 x 1.1 = 12

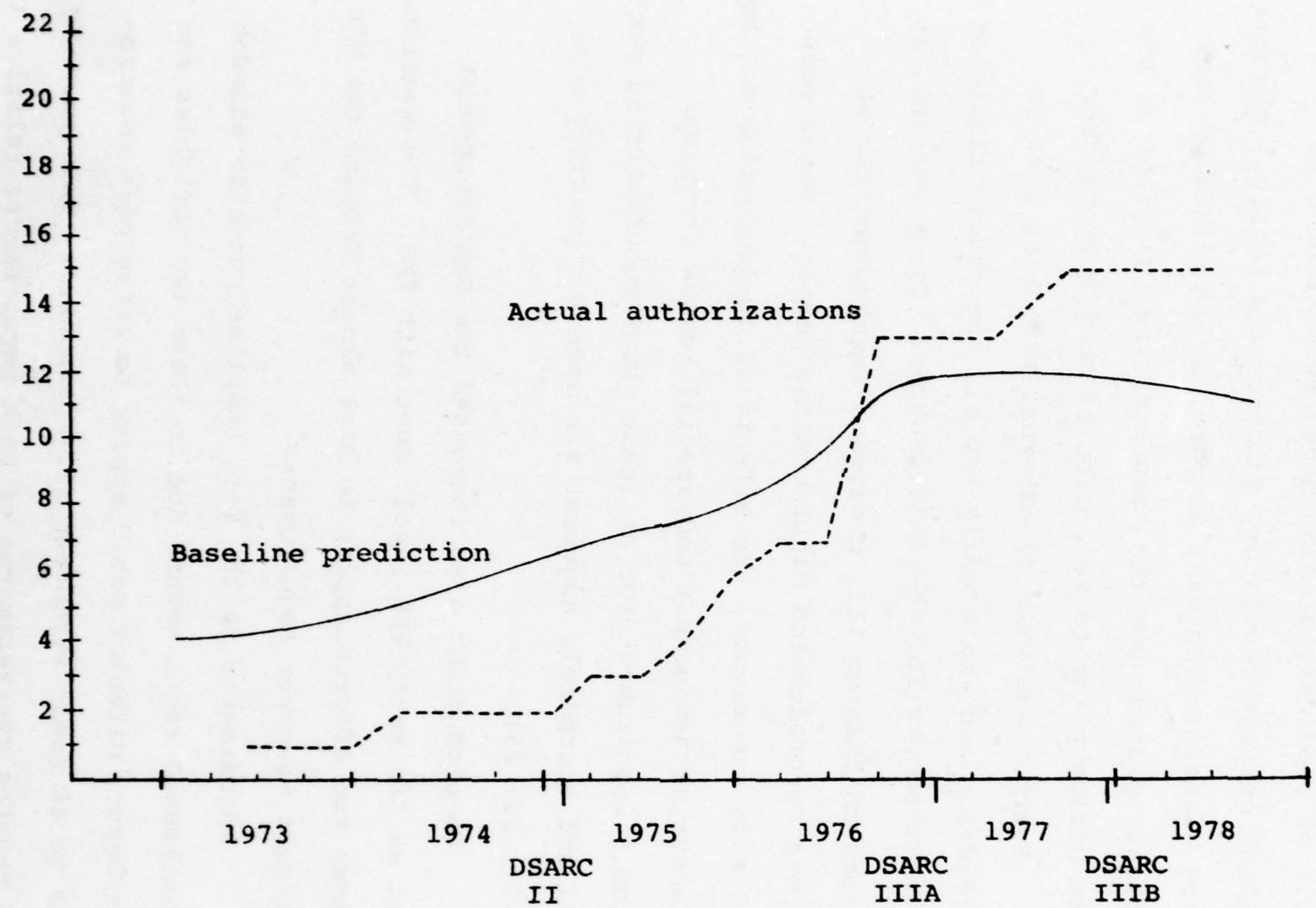


Fig. 19. F-16 Manpower Comparisons

The early overestimates, as in other programs, are a result of predictions being based upon manning to accomplish current regulatory guidance and policy. The low level of authorization can, in part, be explained by lack of emphasis placed upon the manufacturing functions in the program office prior to selection of an FSD contractor.

Further analysis of external variables such as co-production and FMS readily explain the underestimate of peak requirements for the F-16 program. Co-production, as explained in Chapter III, creates a requirement for at least one co-production manufacturing person. Based upon actual F-16 experience, the effects of co-production on the manufacturing management and special review functions created a requirement for at least three manufacturing personnel and a credible argument was made for possibly more (10; 21; 22; 25).

Co-production also increased the GFE management effort as did early FSD involvement with FMS. The magnitude of these two efforts appear to have almost doubled the GFE management manpower requirements.

Adjustments to the F-16 baseline curve to account for increased requirements due to these two variables and for a deputy director would appear to bring peak requirements to at least seventeen (17) personnel. This recomputation creates overestimates of peak requirements relative to actual authorizations.

However, the F-16 manufacturing directorate was also permitted to use non-Air Force manufacturing personnel when conducting special reviews and, to some extent, augment the manufacturing management function. While actual hours expended by these personnel were not ascertained, it appears reasonable that their cumulative effort was greater than that of one full-time person. It also appears reasonable to assume that the augmentation of consultants could have been used to minimize the effect of lagging authorization upon work backlogs as previously discussed.

After all of these adjustments, it appears that the F-16 peak manpower authorizations could have been reasonably predicted at DSARC I and modified prior to FSD source selection. The delay in authorizations can, as in other programs, be explained by the lag in the ASD manpower process.

Summary

This chapter addressed detailed comparisons between predicted manpower requirements (based on information that would have been available at DSARC I) and actual authorizations for the A-10, F-15, and F-16 programs. First, the standard baseline curve was compared to a curve representing the mean manpower authorizations for the three programs. Next, baseline curves for each program

were compared to their respective authorization curves. Finally, differences found in each comparison were analyzed. The findings resulting from these analyses are contained in Chapter V.

CHAPTER V

FINDINGS

Overview

This chapter contains the findings resulting from the analyses in Chapters III and IV. The first section enumerates the findings associated with the analyses of the basic functions and the internal and external variables. The last section contains the findings generated from the comparative analysis of predicted program manpower requirements developed from the standard baseline curve and manpower algorithm, and actual historical manpower authorizations experienced by the A-10, F-15, and F-16 program offices.

Basic Functions and Variables Analyses

Department of Defense, United States Air Force, and Air Force Systems Command policies, directives, regulations, and guidance documents generate the basic manufacturing functions to be accomplished by a major fighter program office. These documents also establish the program phases in which these functions must be accomplished. The basic functions can be categorized as manufacturing engineering, manufacturing management, special reviews, and GFE management.

Key variables, both internal and external to the program office, affect the magnitude of the manufacturing manpower required to accomplish the basic manufacturing functions within a major fighter program office. The internal variables include technical manufacturing risk, co-production, the program office subsystem integration role, and program director philosophy. The external variables include urgency of need, contractor capability, CAS support manning, and FMS.

The technical manufacturing risk of a program and the urgency of need for development both appear to be quantifiable and to provide an objective basis for predicting the minimum manufacturing manpower requirements of a program office. The other variables require subjective analyses to determine their effects upon the magnitude of manpower requirements. A standard program baseline curve and a manpower algorithm based upon the interrelationships among the basic functions and variables were developed and demonstrated to predict manufacturing manpower requirements for a specific program.

Comparative Analyses

Manufacturing manpower authorizations curves developed from A-10 and F-16 historical data revealed relatively low manpower authorization levels during the validation phase and early stages of FSD. These curves

also portray an abrupt increase in peak authorization levels just prior to DSARC IIIA. Additional information also revealed that some of these authorizations remained unfilled until the DSARC IIIA milestones.

The manpower requirements generated from the A-10, F-15, and F-16 program baseline curves consistently predicted:

1. A lower peak manpower requirement than past authorization levels.

2. Higher manpower requirements than actual authorizations until the middle of the FSD phase and lower manpower levels than actual authorizations thereafter.

3. Peak requirements prior to peak authorizations.

Adjustments made to each baseline curve after analyzing the effects of applicable internal and external variables significantly reduced the differences between peak predicted requirements and authorizations. However, early overestimates of authorizations and underestimates of authorizations after IOC still existed.

The early overestimates appear to be due to subsequent changes in regulatory requirements and policies after the validation phases of these programs. The underestimates of authorizations subsequent to IOC may be due to the affects of modification and retrofit activities which were not considered in developing the baseline curves.

Summary

This chapter addressed the findings associated with: the analysis of the interrelationships of the basic functions and the internal and external variables; the development of the algorithm for predicting manpower requirements; and the differences between predicted manpower requirements and actual authorizations for the A-10, F-15, and F-16 programs. Chapter VI contains the conclusions of the research effort, recommendations for the use of the model, and recommendations for further research.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Summary

This research effort was initiated to determine an improved technique for the ASD manufacturing staff to use in assessing manpower requirements for major ASD fighter program offices. Consequently, objectives of this study were: to identify the basic functions and program variables which determine the manufacturing manpower requirements for major ASD fighter programs, and to develop a methodology for predicting short and long term manpower requirements. To accomplish these objectives, the basic functions and key variables were identified through review of applicable documents and personal interviews. Analyses of the interrelationships among these functions were conducted, and a methodology for predicting both future and current manpower requirements was developed.

The first section of this chapter contains the conclusions of this research effort. The final section contains recommendations: (1) for the ASD manufacturing staff in utilizing the resultant methodology, and (2) for future research efforts to improve this methodology.

Conclusions

Basic manufacturing functions were identified through the review of applicable directives, regulations, and policy documents, and through the analyses of ASD matrix organizational responsibilities. Internal and external variables which affect manufacturing manpower requirements were identified from personal interviews with senior manufacturing personnel in the ASD staff and in the A-10, F-15, and F-16 program offices.

Through subsequent analyses of the interrelationships of the basic functions and variables, a methodology for predicting manufacturing manpower requirements for a major fighter program was developed, tested, and partially validated. This methodology can be used early in the acquisition life of a program to predict the minimum manufacturing manpower required to support the program through IOC. As data concerning other variables become known, more accurate manpower requirements can be predicted by considering the effects of these variables upon the manpower requirements. Therefore, the methodology can be used as both a manpower planning tool and as a management tool for annual manpower assessments until program IOC.

Following IOC, the methodology may still be used, but its validity is somewhat questionable. This is due to the increasing disparity between predicted program requirements and actual manpower authorizations.

Two reasons for this disparity appear plausible. One explanation is that modifications and retrofit activities, which were not considered in the model, may have significant effects on manpower requirements after IOC. The other explanation is that actual authorizations are too high. Thus, the methodology should be used with caution after IOC.

Recommendations

ASD Manufacturing Staff

The methodology can be used, as described in Chapter IV, during conceptual and validation phases for initial manpower planning to support new ASD fighter programs. Such predictions, however, should be recognized as minimum requirements subject to change as additional data become available.

The methodology can also be employed to prioritize programs for annual manpower assessments. Data should be solicited from the senior collocate in each fighter program office relative to the existence and status of each previously identified variable. From this data, manpower predictions can be made and compared to each program's authorizations. Programs with the greatest discrepancy in manpower authorizations should be given higher priority for annual reviews. For programs with small discrepancies between predicted requirements and authorizations, the current annual review procedure could possibly be waived.

Further Research

Three areas for further research appear appropriate at this time. These include: (1) performing analyses of the effects of modification and retrofit activities upon manufacturing manpower requirements; (2) determining objective techniques for computing the effects of co-production and FMS upon manufacturing manpower requirements; and (3) developing techniques to rate a DOD contractor's manufacturing and management capability. The resolution of these additional areas should further enhance the predictive value of the methodology presented here.

APPENDICES

APPENDIX A

MULTIPLE LINEAR REGRESSION (MLR) SPECIFICS

This information is included to reflect upon the proposed criteria had MLR been used, and to provide a guide to future research efforts which may be able to overcome the sample size and nonlinearity problems.

Since several of the initially selected variables were classified as nominal, the statistical test must be conducted at both the nominal and interval level depending on the variable. The tests on the nominal variables will measure the cumulative statistical significance of all levels or categories within each nominal variable. Since the ASD manufacturing staff desires a 0.90 confidence level that the model will accurately predict manpower requirements, the data variables should be subjected to T-tests at an $\alpha=0.10$ level of significance.

The level of significance (α) indicates the desired degree of confidence ($1-\alpha$) that one can have that a given variable has contributory significance in predicting or explaining a given outcome. T-tests are statistical techtechniques used to determine whether or not the variable or model under evaluation meets the desired confidence level. Therefore, if a variable is <u>not</u> rejected in a T-test at the 0.10 level of significance, one can be 90 percent confident that the variable is statistically significant in contributing to the predictive efficiency of the model.

The overall efficiency of a model is a measure of how well the model explains (predicts) the differences in outcomes under different conditions. In statistical analysis, the Coefficient of Determination (R^2) is a measure of a model's or variable's efficiency in explaining the total variations of outcomes. The value of R^2 can vary from zero to one with increasing values directly proportional to the model's or variable's explanatory power of total variations. For example, an R^2 equal to 0.70 means that 70 percent of the total variation of predicted outcomes is explained by the model. Since each management situation is unique, there are no definite rules to be used in selecting the most appropriate acceptable R^2 for a mathematical model. The appropriate R^2 has to be determined by the analyst and his client. For example, if the manager has other tools to use in conjunction with the mathematical model, he can accept a lower R^2 than if the mathematical model is his only tool. Since the predictive power of a mathematical model varies between 0.0 and 1.0 (no predictive power to perfect predictive power, respectively), the desired degree of predictive power and the intended use of the model determine the range of acceptable R^2 values. Ideally, one would always want an R^2 of 1.0; however, the costs of obtaining that level is normally very high and thus trade-offs have to be made between predictive power and its associated costs.

In terms of the Air Force Manpower Engineering Program (MEP), the contemplated model would generate Type II statistical standards. The primary reasons for this classification stem from the following reasons:

1. Data does not specify military/civilian grades or skills;

2. Data is based on historical manpower records; and

3. The description of authorized work performed is similar to program mission statements for program elements.

Consequently, there are no specified minimum requirements for R^2 (9:1-1 thru 17-7).

For this research an R^2 range from 0.70 to 1.00 should be the target. The minimum value of 0.70 was chosen after various discussions with the manufacturing staff as to the use of the model. An R^2 of 0.80 or better would enhance the use of the model as a management tool, but an R^2 of 0.70 should still be acceptable. Although the MEP establishes no minimum R^2, values below 0.70 are questionable since, in this situation, the model would only be a marginal improvement over existing procedures. Therefore, the model would be considered a valid tool for predicting manufacturing manpower requirements if the overall model exhibits an R^2 of 0.70 or better at the 0.10 level of significance. This means that the model would be accepted as

valid if one can be 90 percent confident that the model will be 70 percent efficient in predicting future outcomes.

An R^2 of less than 0.70 may be considered inefficient in practical application since more than 30 percent of the remaining variations would have to be explained by subjective analysis of the ASD manufacturing staff (16).

Once the appropriate variables have been identified, they should be included in a model until an R^2 of 0.70 is attained. Retaining a variable after this level of explanatory power has been reached must be determined by each variable's statistical significance, its marginal explanatory contributions to the overall model, and the cost of collecting and employing associated data.

APPENDIX B

SYSTEMS DYNAMICS APPLICATION (18)

Systems dynamics is a simulation technique which can be used to enhance the understanding of complex managerial situations and to test the effects of various policy changes. While not designed to give precise answers, systems dynamics does permit the behavior of a system composed of interacting feedback loops to be depicted.

In building a systems dynamics model, the designer normally goes through four steps: (1) develop causal loop diagrams, (2) convert the causal loop diagrams into flow diagrams, (3) write a computer simulation program, and (4) run the computer program to test the effects of various policy decisions. Since this is a building block process, the designer can stop at any point in the process and still provide meaningful information. The degree of completion is a function of the purpose of the analysis and output desired; i.e., understanding of the structure of a system or actually testing certain policies, changes, and so forth.

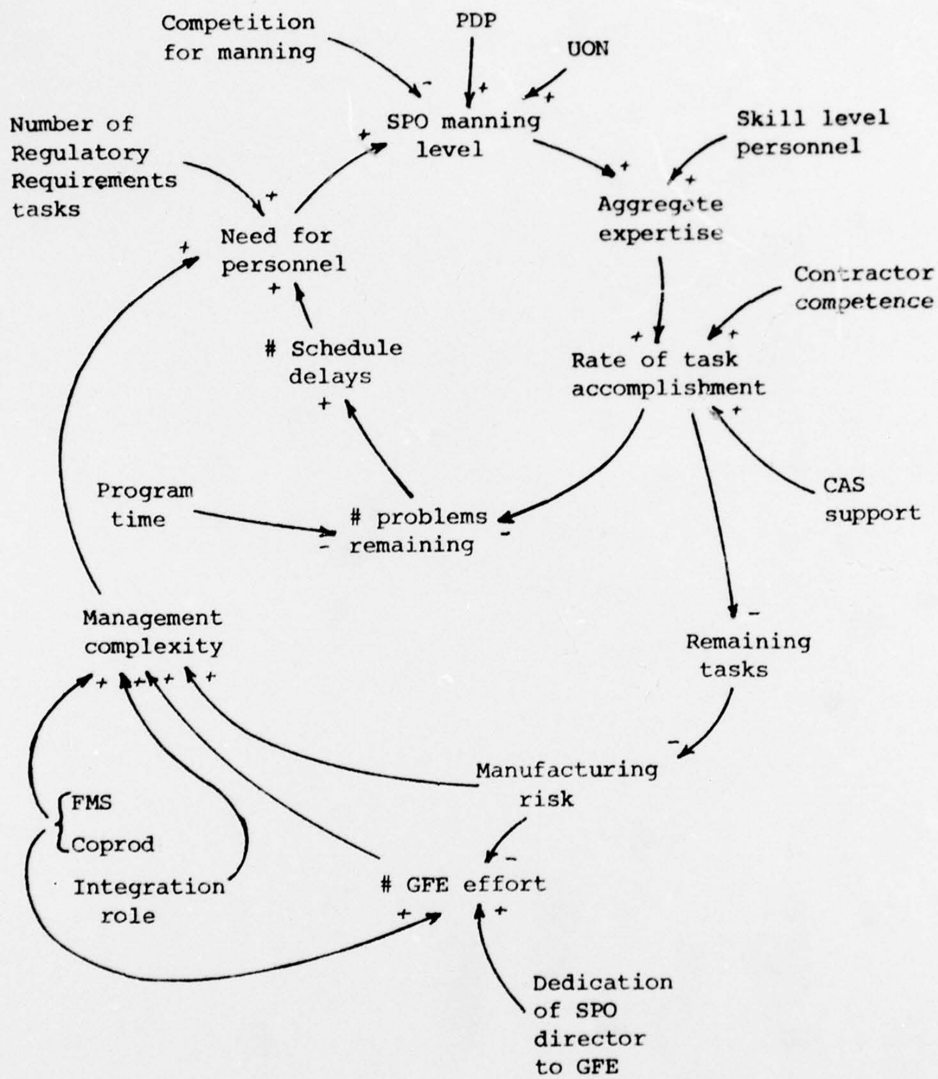
Since it is not the intent of this annex to provide an understanding of systems dynamics, only a limited discussion is provided in an attempt to enhance the understanding of the manufacturing manpower management process at ASD.

Thus, only the first step of the systems dynamic technique (generation of causal loop diagrams) is necessary

to show the complex interrelationships which exist in determining manufacturing manpower requirements to support a major fighter program at ASD.

As is evident from the causal loop diagram, many of the variables are beyond the realm of the SPO director's control, but they all affect his manpower levels and, consequently, his success in accomplishing his tasks.

Within ASD, the manufacturing personnel resources are matrixed and come under the responsibility of a home office as well as the SPO director. Thus, if these resources are to be efficiently managed, both the staff and SPO director must understand the processes in the manpower structure. The causal loop diagram is included to supplement the analyses in this study by providing a slightly different perspective. The intent is to further the understanding of the interaction of the functions and variables discussed in the study and, if desired, to provide a basis for developing a computer program.



+ = direct relationship
- = inverse relationship

Fig. 20. Manufacturing Management Causal Loop Diagram

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